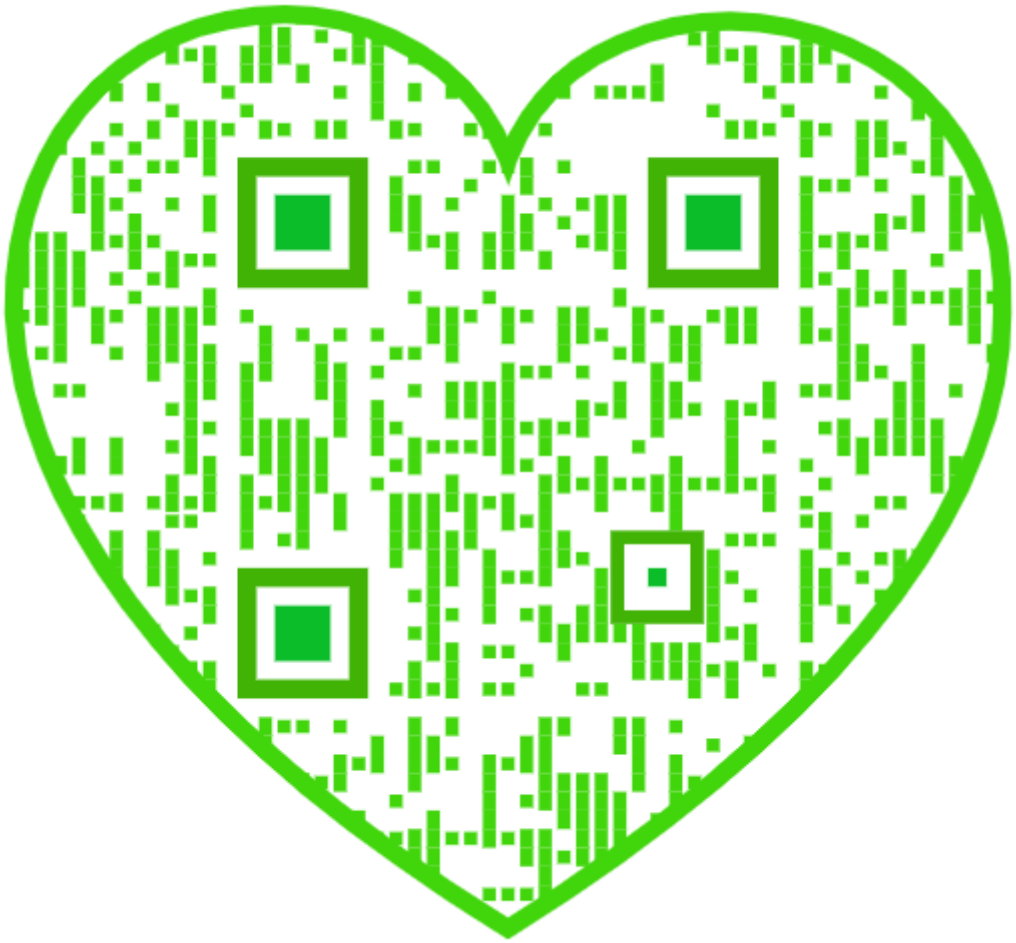

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BOILER-WATERS

SCALE, CORROSION, FOAMING

BY

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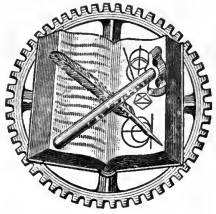
SEVENTY-SEVEN ILLUSTRATIONS



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A.S.P.

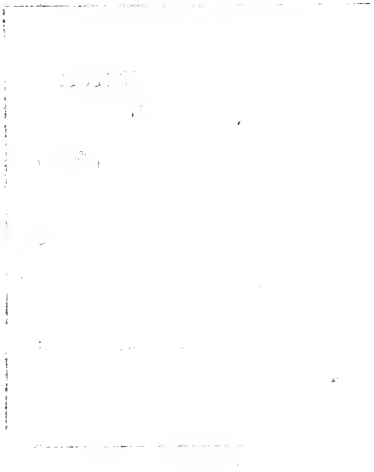
A steam-boiler is a steam-generator, not a kettle for chemical reaction.

"Get, if possible, a supply of clean, soft, natural water."

"The only compound to put into a boiler is pure water."

Oxygen, the most useful element, is, when free in boilers, a most destructive corrosive element.

161878



PREFACE.

THE relative value of one boiler to another may, in many cases, be measured by its scale-forming propensity with a given water.

Purify this water and all boilers come much nearer a uniform value per unit of heating-surface.

This work has for its object to furnish steam-users with information regarding water, its use, and troubles arising from the use of water, and remedies that may be used or applied; the gain being more efficient generation of steam.

It is due to the Railway Master Mechanics' Association that real progress has been made in the softening of water for locomotives, along which line much work is being done, and the same line of work is now being taken up by manufacturers and industrial corporations.

The author wishes to thank all who have aided him in his work; credit has been given, as far as possible, to those to whom credit is due, and he sends the book forth as a pioneer on the subject in this country, and he will be glad to receive suggestions, just criticisms, and new material looking toward a more perfect and rounded-out work in the near future.

WILLIAM WALLACE CHRISTIE.

PATERSON, N. J., Oct. 1st, 1906.

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LIBRARY OF THE UNIVERSITY OF CALIFORNIA

BOILER-WATERS.

CHAPTER I.

WATER, ITS PROPERTIES, MATERIALS FOUND IN WATER, WATER ANALYSIS.

STEAM-MAKING is the important thing in all steam-plants; next in importance to the boilers themselves is the water to be evaporated as steam.

Water is a combination of the two very abundant elements, hydrogen and oxygen, in the proportion of two parts hydrogen by volume to one part oxygen (H_2O); it is also one part by weight of hydrogen to eight parts of oxygen.

All living things, plant and animal, contain a large proportion of water.

Water as used in power-plants is seldom sent to the boiler in a proper condition of purity, as is evidenced by the large number of boilers in which scale or corrosion is found.

Distilled water should not be used unless a certain amount of raw water be added to it at regular intervals to prevent entirely or lessen its corrosive action.

The most desirable feed-water is soft water, either that naturally soft or water that has been treated by one of the many methods of water-softening now in use, which destroy scale-forming properties.

Rain-water, a water we should think would come to us pure, is never entirely so, frequently containing one to three parts of inorganic impurities per 100,000 parts of water.

Snow and rain always contain gases of atmospheric origin, among which are oxygen, nitrogen, and carbonic acid.*

	Water Falling at Paris. Grams per Cubic Meter.	
Nitrogen	6.397	7.939
Ammonia	3.334	2.769
Nitric acid	14.069	21.800
Chlorine	2.081	1.946
Lime	6.220	5.397
Magnesium	2.100	2.300

In addition to gases, we find in water the salts of ammonium, sodium, and calcium.

Rain-water we may say in a general way is the purest of all natural waters.

From seventy-one samples of water collected at a farm at Rothamsted, England, we have for an average:

Total dissolved solids	3.95	parts per 100,000
Organic carbon	0.099	
Organic nitrogen	0.022	
Ammonia	0.050	
Nitrogen as nitrates and nitrites	0.007	
Total combined nitrogen	0.071	
Chlorine	0.063	

From Massachusetts we have this analysis of polluted river-water:

Turbidity		slight
Color		1.5
Nitrogen as	Albuminoid ammonia	0.263
	Free ammonia	0.664
	Nitrites	0.025
	Nitrates	0.800
Chlorine		24.1
Total residue		127.0

All in parts per million.

The waters of many rivers are contaminated with much coloring-matter and other organic matter in suspension, which can be readily filtered out and save much trouble in the boiler.

---

* De La Coux, p. 8.

The same remark will apply if we leave certain organic matter in the water, as we shall see later is the case with river-water at Pittsburg, Pa.

ANALYSIS OF WELL-WATER.*

(U. S. Government Wells, Sandy Hook, N. J.)

	Machine-shop.	Officers' Quarters.	
Sulphuric acid	.0352	.0170	Grams per liter.
Chlorine	.0225	.0142	
Silica	.0014	.0013	Soluble residue, grams per liter.
Iron and alumina	.0005	.0012	
Lime	.0109	.0127	
Magnesia	.0053	.0117	
Soda	.0419	.0296	
Potash	.0042	.0003	
Silica	.0074	.0087	Insoluble residue, grams per liter.
Iron and alumina	.0015	.0024	
Lime	.0408	.0412	
Magnesia	.0083	.0064	

IMPURITIES IN NATURAL WATERS.†

- **Suspended matter**
  - Inorganic or mineral — Sand, clay, and various pulverized minerals.
  - Organic
    - Animal — Living microscopic animals; dead fish and parts thereof; feathers from birds, etc.; decayed animal refuse; hair; manufacturing wastes, such as wool-scourings, dyehouse wastes, blood from slaughter-houses, etc.; excrement and urine from sewers, etc.
    - Vegetable — Dried leaves, grass, flowers; decayed wood; peaty matter; algæ and other plant life, including bacteria; wastes from cotton-, silk-, and linen-mills, and from distilleries, etc.
- **Dissolved matter**
  - Gaseous — Carbon dioxide; Hydrogen disulphide.
  - Solid
    - Inorganic metals in general.
    - Organic — Animal—see above; Vegetable—see above.

* U. S. Government Tests, 1886, p. 4.

† From W. S. and I. P., No. 79, U. S. Geological Survey.

Spring-water, like well-water, is frequently impregnated with carbonic-acid gas, which comes from the organic matter in the earth.

The water obtained from the granitic rocks is purer than that from the secondary strata, which latter is calcareous in its make-up.

Unfiltered and filtered water may contain certain of the chemical elements, such as sodium, calcium, potassium, etc., which remain in solution at the ordinary or lower temperatures, but which decompose when subjected to the high temperatures from furnace-fires, and which elements fall to the shells or tubes of boilers as a fine powder or, what is more frequent, adhere to the tubes and shell as scale.

Some spring-waters contain zinc;* for example, one in southern Missouri has this analysis:

	Parts per Million.		Parts per Million.
$PbSO_4$	trace	$CaSO_4$	109.9
$CuSO_4$	0.5	$MgSO_4$	19.0
$CdSO_4$	0.9	K_2SO_4	5.6
$ZnSO_4$	297.7	Na_2SO_4	5.9
$FeSO_4$	1.6	NaCl	4.3
$MnSO_4$	6.3	$CaCO_3$	72.0
$Al_2(SO_4)_3$	2.5	SiO_2	13.7

Compressibility of Water.—Water is but slightly compressible: for each foot of pressure distilled water will be diminished .0000015 to .0000013 in volume.

At a depth of half a mile, 2640 feet, a cubic foot weighs only about one quarter of a pound more than at the surface.

The freezing-point of water is at 32° F. at the ordinary atmospheric pressure—sea-level—and ice melts at the same temperature.

Sea-water freezes at 27° F., and the ice is fresh. The usual sources of water are:

1. Rain or melted snow;
2. Lakes, rivers, or creeks;
3. Wells, driven or dug;
4. Mineral springs;
5. Ocean- or sea-water;

---

* Hillebrand, Bul. 113, U. S. Geol. Survey.

and the forms of water commonly known to us are

(*a*) Solid form—Ice;

(*b*) Liquid form—Water;

(*c*) Gaseous form—Steam.

Though water is used for domestic purposes, and for washing in its broad sense, and to sustain life, it is only its use in steam-boilers—steam-making—that we shall consider in this book.

Peaty water from woodlands has a solvent action on lead pipes due to its acidity, which varies in terms of a sulphuric acid equivalent from 1 to 4 parts in 100,000.

Mr. Ackroyd says that the solvent action would not occur if the acidity did not exceed 0.5 part in 100,000.

High velocity of steam-particles is considered favorable to both corrosion and incrustation.

Oxygen Dissolved in Water.—Nearly all waters contain oxygen in solution.

Spenmath states that water absorbs oxygen as follows:

At 32° F. it absorbs 4.9 per cent of its own bulk;

At 50° F. it absorbs 3.8 per cent of its own bulk;

At 68° F. it absorbs 3.1 per cent of its own bulk.

Stromeyer states that under 150 pounds pressure cold feed-water absorbs 3.2 pounds of oxygen per ton of water.

ABSORPTION OF GASES.

	Coefficients of Absorption in Water.	
	At 0° C. (32° F.)	At 20° C. (68° F.)
Nitrogen.	0.02035	0.01403
Carbonic acid.	1.7967	0.9014
Oxygen.	0.04114	0.02838
Atmospheric air.	0.02471	0.01704

Figure 1*a* is a graphic representation of the relation of temperature to the evolution of mixed gases in water under atmospheric pressure, and is taken from a paper read before the Victorian Institute of Engineers, Australia, by Mr. James Alex. Smith.

The water used in making the determinations was the ordinary "Yan Yean" supplied to Melbourne, Australia, and which is, chemically, almost a natural distilled water.

Gases were expelled from unit volume of water.
Gases previously absorbed from the atmosphere at 54° F.
Composition of gases: Oxygen 31, nitrogen 69 per cent.
Barometer, 29.9 in.

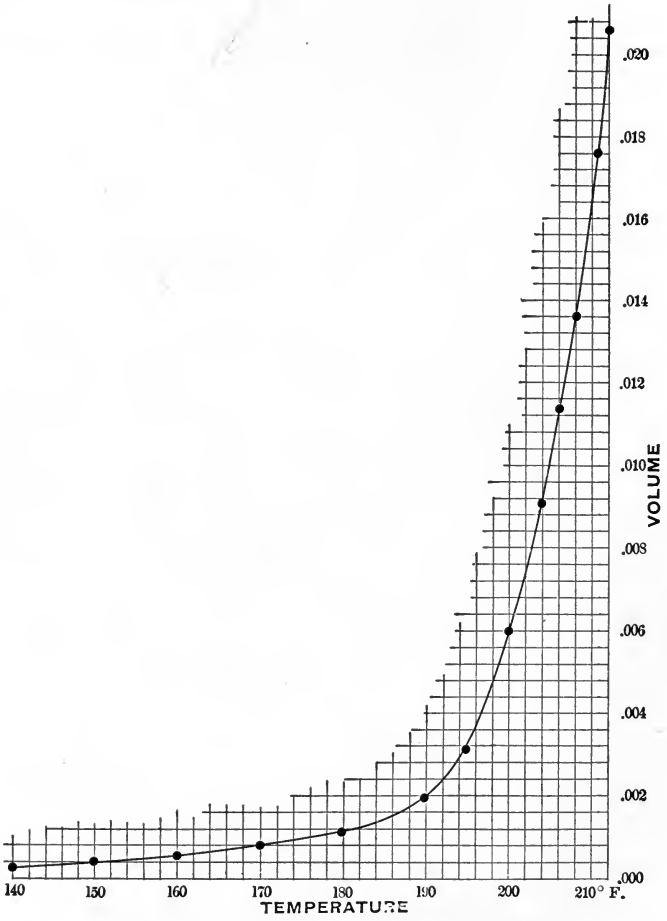

FIG. 1*a*.—Temperature-gas-emission Curve.

Temperature of water raised from 54° F., and steadily increased to 212° F. in one hundred and fifty (150) minutes.

First evolution of gas at 120°.

Mr. Smith says that "known facts relating to feed-pipes, econo-

mizer tubes, and those parts of boilers near the inlet amply prove that marked oxidation may ensue when the gases are released by temperature increment and whilst they still continue in a constricted fluid flow, in contact with relatively large bounding superficies."

Atmospheric air contains only $\frac{1}{4000}$ of carbonic acid, whereas the air held in solution in water contains from 40 to 42 per cent of carbonic acid. The boiling-point of water depends on the substances it contains in solution, or, in other words, depends upon its purity, also upon the atmospheric pressure or pressure in vessels containing the water.

Water containing sodium chloride has the boiling-point raised in proportion to its salinity as shown in the following table:*

	Deg. C.	Deg. F.
Pure water	100	212
Water containing 5 per cent of sodium chloride	101	213.8
" " 10 " " " " "	103.0	217.5
" " 15 " " " " "	104.6	220
" " 20 " " " " "	106.3	223.5
" " 25 " " " " "	107.9	226.3

A solution containing 30 per cent of magnesium chloride boils at 115.6° C. (240° F.).

Sea-water is very much like deep well-water, having many substances in common. There are certain salts in each which are especially corrosive and scale-forming. They are:

Scale-forming
- Sulphate of calcium.
- Sulphate of magnesium.

Corrosive
- Chloride of sodium (In presence of calcium and magnesium salts.)
- Chloride of magnesium.
- Chloride of calcium.
- Chloride of potassium.

Sulphate of calcium, a very troublesome scale-forming salt, is decidedly prevalent in both sea- and well-waters.

Calcium Sulphate,† $CaSO_4$.—Calcium sulphate, known as gypsum, or plaster of Paris, is slightly soluble in salt water or pure

* De La Coux, p. 34.

† See Eng. News, vol. 40, 403.

water at temperatures between 140° and 150° C. (284° and 302° F.) and beyond; precipitation which has been started by heating the solution to 140°–150° C. (284°–302° F.) continues even after the water has been cooled. Below 284° F. the lower the temperature the greater the solubility.

TABLE OF SOLUBILITY OF CALCIUM SULPHATE IN 100 PARTS OF WATER AT HIGH TEMPERATURES.

Temperature, deg. C..	140	165	175–185	240	250
" " F..	284	329	347–365	464	482
Parts $CaSO_4$.....	0.078	0.056	0.027	0.018	0.016

Precipitation of $CaSO_4$ is in the form of heavy crystals. It is a very poor conductor of heat. Being soluble in water free from carbonic-acid gas at the moderately low temperatures, it can be removed by means of carbonate of soda—soda-ash. The chemistry of the reaction is $CaSO_4+Na_2CO_3=$, after being dissolved in water and mixed, $CaCO_3+Na_2SO_4$. $CaCO_3$ settles as a white precipitate. Caustic soda may also be used, but gives a slightly different reaction.

Prof. V. B. Lewes * has found by experiment that if sea-water is diluted a thousand times its own bulk with distilled water, the minute trace of calcium sulphate will separate in a thin pellicle, which attaches itself to the side of the vessel when a temperature of 300° F. is reached, at which temperature all of the calcium sulphate will separate out, though more slowly than at higher temperatures.

G. M. Davidson states that calcium sulphate is much more harmful to boilers than large quantities of sodium sulphate, provided the calcium sulphate does not run, say, above 150 grains per gallon.

Sodium sulphate can be removed by blowing off or washing out; calcium sulphate once precipitated can only be removed with great difficulty. It forms no scale in the pipes of the fuel-economizer, the temperatures attained in the water not being sufficiently high. Its deposition in boilers is due to the slow concentration of the water and higher temperatures reached in them.

Calcium sulphate in boiler-waters causes hard incrustation

* V. 30, 345 Inst. Nav. Archs.

which is difficult to remove, and causes a noticeable loss in evaporative efficiency of the boiler. It also becomes mixed with mud in the boiler and renders the resultant scale hard.

Water temporarily hard, with the proper handling of the boiler gives a loose powdery or sludge deposit, such hardness being due to calcium and magnesium carbonates.

Water permanently hard, usually due to calcium sulphate, generally produces a hard scale, and one of the most objectionable of scales, especially due to the fact that it becomes less soluble in water at the higher temperatures, as given by the following table.

SOLUBILITIES IN GRAINS PER GALLON (ENGLISH).*

Temperature, Degrees F.	Corresponding Steam Pressure, Pounds.	Chemicals and Experimenters.			
		Calcium Oxide.†	Calcium Sulphate.		
		Lanny, 1878.	Marignac, 1874.	Poggiale, 1879.	Tilden and Shenstone.
32	.....	96.7	133.0	143.5	
40	.....	94.0			
59	.....	91.0			
64.4	.....	.....	143.0		
68	.....	.....	.....	168.7	
75.2	.....	.....	146.5		
86	.....	81.4			
95	.....	.....	.....	177.8	
101.5	.....	.....	150.3		
111	.....	70.1			
127.4	.....	.....	147.0		
140	.....	70.8			
158	.....	.....	.....	170.8	
161.6	.....	.....	140.8		
210.2	.....	.....	122.6		
212	0	40.2	.....	151	
284	37	.....	.....	.....	54.6
323.6	79	.....	.....	.....	39.2
356	131	.....	.....	.....	18.9
464	484	.....	.....	.....	12.6
482	575	.....	.....	.....	12.6

* Engineering, Dec. 25, 1903. † Caustic lime.

Calcium Carbonate, $CaCO_3$.—Calcium carbonate, commonly known as limestone, marble, or chalk, is readily soluble in water containing carbonic-acid gas, is more soluble in cold than in hot water.

When recently precipitated it is soluble in 8834 parts of boiling water, in 10,601 parts of cold water, and at a temperature of 15° C. (59° F.) is soluble in 12,858 parts of water; another authority says it is soluble in 16,000 to 24,000 parts of pure water. It does not form a very hard scale, but is sometimes bulky upon crystallization.

Carbonate of lime is held in solution in water which contains carbonic-acid gas, so that any chemical which will take up the carbonic-acid gas will precipitate the calcium carbonate. The most frequently used chemical for this purpose is common building-lime, or quicklime as it is called. It unites with the water and forms a new substance—hydrate of lime, or slaked lime—which takes up the carbonic-acid gas and forms calcium carbonate, which being then insoluble, is all precipitated as a white powder.

Carbonate of lime forms a hard scale in economizers and a soft mud in boilers, unless sulphate of lime is present, when it also is cemented into a scale.

When the carbonate of lime is precipitated out of water it first appears as a bluish-white thin starch, which can readily pass through the best chemical filters, not being arrested by wood-wool, cloth, or sponges. If allowed to stand or be slightly heated, the color changes to yellow, and no amount of shaking will change it back; it likewise settles very slowly. Prof. Wanklyn's experiments give 25 minutes for this precipitate to settle through $\frac{3}{4}$ inch of water, 8 hours or 480 minutes to clear up 20 inches depth of water; the rate of settlement being 1.8 to 2.5 inches per hour with the water cold. We can thus see why large settling-tanks are necessary when working with cold water.

If the raw water is heated, as is done in some of the softening processes, the settling-tank is made smaller.

Sulphate of lime and magnesium hydrate form the hardest kind of a scale; a scale of this kind has the following composition:

Carbonate of lime	2.490 per cent
Sulphate of lime	74.280 " "
Magnesium hydrate	18.000 " "
Alumina and oxide of iron	1.276 " "
Silica	1.830 " "
Organic matter	2.124 " "
	100.000 per cent

This scale had to be chipped from the boiler-shell.

Six specimens of incrustations analyzed by Prof. Chandler gave for averages:

Sulphate of lime	56.49 per cent
Carbonate of lime	18.11 " "
Basic carbonate of magnesia	19.77 " "
Oxide of iron and aluminium	0.69 " "
Silica	3.81 " "
Organic matter	not determined
Water	1.62 per cent
	100.00 per cent

Magnesium Sulphate, $MgSO_4$.—Magnesium sulphate, or Epsom salts, is very slowly soluble in cold water, and easily soluble in warm water; is very common and decomposes at high temperatures, forming scale. At the higher temperatures the solubility increases as the temperature. It does not of itself form boiler-scale, but when in a boiler containing carbonate of lime a chemical reaction takes place, when hydrate of magnesia and calcium sulphate are formed. These two compounds form a very hard and stony scale.

The sulphate and carbonates of calcium cause most all of the scale troubles in boilers.

Rankine in his "Mechanics" gives this table of resistance to passage of heat of various substances:

Wrought iron	1
Copper	0.4
Slate	9.5
Brick	16.7
Calcium carbonate	17
Calcium sulphate	48

Magnesium Carbonate, $MgCO_3$.—Magnesium carbonate, or magnesia, is insoluble in water. Like carbonate of lime, it is held in solution by carbonic-acid gas, and is precipitated when the gas is driven off by the use of slaked lime.

This substance forms the principal ingredient of a well-known steam-pipe covering, and is there used to keep the heat in the pipes; it should be kept out of the boiler's interior parts as scale; that is, out of all the water-surface in the tubes, shell, and all parts of the boiler itself.

Magnesium Chloride, $MgCl_2$.—Magnesium chloride is very soluble in water, and evolves heat when in solution. 1 part is soluble in one part of cold water; 1 part is soluble in 1.857 parts of water at 15° C. (59° F.).

Sodium Sulphate, Na_2SO_4.—One part of sodium sulphate is soluble in 7.367 parts of water at 15° C. (59° F.). 100 parts of water at 0° C. (32° F.) dissolve 5.155 parts of sodium sulphate; at 100°.6 C. (213° F.) 100 parts of water dissolve 45.985 parts of sodium sulphate. The maximum solubility is at 33° C. (91°.5 F.). The solubility is least at 103°.17 C. or 218° F.

SOLUBILITY OF Na_2SO_4 IN WATER AT THE VARIOUS TEMPERATURES AND PRESSURES.*

Parts of Na_2SO_4 contained in 100 parts of the saturated solution at pressure *A* in atmospheres.

A.	0° C. (32° F.)	15° C. (59° F.)	15.4° C. (59.75° F.)
1	4.40	11.32	11.4
20	4.53	10.78	10.74
30	....	10.05	
40	....	10.33	

Where sulphate of soda is present in excessive quantities in boilers, the frequent use of the blow-off cock will remove the concentrated solution and prevent foaming.

Sodium Carbonate, Na_2CO_3.—Sodium carbonate, known as "soda crystals," washing-soda, Scotch soda, or soda-ash, is soluble in water with evolution of heat. One part is soluble in 2 to 5.967 parts of water at 15° C. (59° F.). It possesses four different degrees of rapidity of solubility, due to varying quantities of water of crystallization, and is but little more soluble at 34°–38° C. (93°.2–100°.4 F.) than at 104° C. (219°.2 F.).

A saturated solution forms a crust at 104°.1 C. (219°.2 F.), and contains 42.2 parts of sodium carbonate to 100 parts of water. The highest temperature observations were at 105° C. (221° F.).

Soda-ash is a dry, sometimes impure carbonate, and is used where a cheap reagent is wanted in large quantities, and is not adapted to "cold-process" treatments. Flynt † says that soda-

* Möller. † Eng. Mag., 1903.

ash, if used to treat water which is " hard " because of bicarbonates with free carbonic acid dissolved, can only be used in conjunction with lime, and then in the purification of waters which contain silicates or sulphates only, either or both.

Muddiness in the water as seen in the gauge-glasses is a sure test if too much soda-ash is being used, and when this is noticed and acted upon there should be no further trouble from material passing over to the engine-cylinders.

Sodium Chloride, NaCl.—Sodium chloride, or common salt, is always present in sea-water, and is frequently found in artesian-well water when wells are driven near sea or ocean. It is soluble in water; 36 parts of sodium chloride mixed with 100 parts of water at 12°.6 C. (54°.7 F.) lowers the temperature 2°.5 C. (4°.5 F.). The presence of other salts increases the solubility of sodium chloride in water.

SOLUBILITY OF NaCl IN 100 PARTS OF WATER AT GIVEN TEMPERATURES.*

Temperature.		Parts NaCl.	Temperature.		Parts NaCl.
Deg. C.	Deg. F.		Deg. C.	Deg. F.	
−15	5	32.73	40	104	36.64
−10	14	33.49	50	122	36.98
− 5	23	34.22	60	140	37.25
0	32	35.52	70	158	37.88
5	41	35.63	80	176	38.22
9	48.2	35.74	90	194	38.87
14	57.2	35.87	100	212	39.61
25	77	36.13	109.7	229.5	40.35

* Poggiale.

Another table gives these figures:

At 32° F. 20,849 grains NaCl dissolved per gallon
" 68° F. 21,014 " " " " "
" 122° F. 21,598 " " " " "
" 167° F. 22,182 " " " " "
" 194° F. 22,767 " " " " "
" 220° F. 23,349 " " " " "
" 239° F. 23,640 " " " " "

Silica.—Silica is never dissolved in large quantities in steam-boiler water, and but little is present in scale, but it is often combined with alumina.

With other impurities in time there is formed a jelly-like paste, changing under heat to a white, laminated mass, undulating in its surface, which can be detached by scraping from the shell of the boiler.

Heat eventually bakes it into a hard crust, removed by chipping.

Silica is easily precipitated by boiling the water at atmospheric pressure, and it is occasionally found in liberal proportions in low-pressure boilers with sulphate of lime.

Silicic Acid, SiO_2.—Silicic acid is soluble in 1000 parts of pure H_2O, water.

Oxides of Iron and Aluminium, Fe_2O_3 and Al_2O_3.—Fe_2O_3, oxide of iron, is formed at 110°–140° C. (230°–284° F.), and is insoluble in water, H_2O, or in solutions of alkalies. Al_2O_3, aluminium oxide, is insoluble in acids and soluble in water.

Caustic Baryta, $Ba(OH)_2$.—Caustic baryta is said by H. de la Coux to be an admirable remedy for encrusting-corrosive waters, sea-water and deep-well water. It transforms sulphate of calcium into sulphate of barium, which does not adhere to the boiler-plates. As to corrosion it acts energetically; for instance, with chloride of magnesium at boiling-point magnesium oxide is rapidly precipitated. The chloride of barium then obtained precipitates the sulphate of calcium in turn. It is much better to use, under the above conditions, than lime, which increases scale rather than preventing it when used in excess.

Carbonate of Barium (Witherite).—Carbonate of barium, a by-product of sugar-refineries, may be used to advantage with deep-well waters, as, even cold, it precipitates the metallic oxides of the salts which are very injurious, such as sulphate of iron and aluminium. It is also used to treat water too high in sulphates. It adds nothing to the water, and with calcium sulphate forms barium sulphate, which is precipitated, and calcium carbonate, which also is readily precipitated. It is used for waters high in sulphates or free sulphuric acid.

Glycerine.—H. de la Coux says that the use of glycerine as recommended by Asselin and P. Videt depends upon the great solubility of the calcic salts in this agent. When the water by

continued evaporation contains too great a quantity of calcic salts for the glycerine salts, the salts of the alkaline earths, instead of forming adhesive scale, take a gelatinous form and will not adhere to the boiler-plates.

Acids.—Acids have been described as salts of hydrogen; and those acids most common have these properties:

1. Solubility in water;
2. A sour taste (even after great dilution);
3. Reddening organic blue, etc.;
4. The power of decomposing most carbonates, causing effervescence;
5. The power of destroying the characteristics of alkalies and forming alkaline salts.

Sulphate of aluminium and potassium (alum) possesses all of the above characteristics, though it is not an acid. Sewage contains ammonia, which, as a gas, escapes from the water or permeates it, and neutralizes the carbonic-acid gas.

Wood Extracts.—We frequently hear of wood chips or chunks of wood of different varieties being placed directly in the boiler; neither, however, is as satisfactory as the use of the wood extract. Logwood or oak wood is frequently used; but the quantity, as for any other material, must be determined for each water used.

There are many mixtures called boiler compounds used for the purpose of preventing scale. De la Coux recommends: Boil 2 kilograms of oak sawdust for an hour, at least, in 10 liters of water, then add 3 kilograms of molasses. A kilogram per H.P. per week is usually sufficient.

Solubility.—Schwackhöfer says that although the solubility of solid bodies rises, as a rule, with the temperature, the following points must be noted:

1. Solubility increases at a very slow rate, the behavior of chloride of sodium being one of few exceptions.

2. Solubility is proportional to the increase of temperature (in chloride and sulphate of potassium, sulphate of magnesium, and chloride of barium).

3. Solubility, as a rule, takes place at a quicker rate than the temperature rises (e.g., nitrate of potassium, nitrate of lead, sugar, etc.).

4. Solubility sometimes increases with increase of temperature up to a certain point, but diminishes after that point has been reached (sulphate of soda).

5. Finally, solubility sometimes diminishes with increasing temperature (sulphate of calcium).

TABLE OF SOLUBILITIES.

Quantity of substance that one English * gallon of pure water can dissolve.

Substance.	At 60° F.	At 212° F.
Alum (potash alum)	0.95 lbs.	35.7 lbs.
Aluminium sulphate	3.3 "	8.9 "
Ammonium oxalate	0.45 "	4.08 "
Barium chloride	3.5 "	6.0 "
" hydrate	0.5 "	1.0 "
Calcium carbonate †	2.5 grains	1.5 grains
" chloride	40.0 lbs.	unlimited
" hydrate	93.0 grains	53.6 grains
" nitrate	40.0 lbs.	unlimited
" oxide (lime)	70.0 grains	40.5 grains
" sulphate ‡	161.0 "	152.0 "
Ferrous sulphate	2.0 lbs.	17.8 lbs.
Magnesium carbonate	doubtful	1.5 grains
" chloride §	20.0 lbs.	40.0 lbs.
" hydrate	2.0 grains	2.0 grains
" oxide	1.4 "	1.4 "
" sulphate	3.0 lbs.	13.0 lbs.
Sodium biborate (borax)	0.4 "	5.5 "
" carbonate (dry)	1.2 "	4.5 "
" " (crystals)	4.1 "	14.0 "
" chloride	3.5 "	4.0 "
" hydrate	6.1 "	unlimited
" hyposulphite	5.0 "	20.0 lbs.
" phosphate	1.2 "	20.0 "
" sulphite	2.5 "	10.0 "
" sulphate	1.1 "	4.2 "

* For an American gallon reduce each amount by 16.7 per cent.

† Insoluble at about 290° F.

‡ Decomposes at boiler temperatures in presence of alkaline earths or iron.

§ Insoluble at 302° F., equal to 70 lbs. steam pressure.

Chemical Analysis.—Many times when we are away from the large business centres it is desired to test the feed-water, without employing a chemist, to find out just what chemicals are needed to make the water the best for our use.

We will need a few test-tubes and the materials called for on the following list.

LIST OF CHEMICALS AND APPARATUS.

½-pint bottle of soap solution;
1 2-oz. bottle of lime-water;
1 " " " chloride of barium;
1 " " " chloride of ammonium;
1 " " " ferrocyanide of potassium;
1 " " " hydrochloric acid;
1 " " " nitric acid;
1 " " " tincture of cochineal;
1 " " " metallic mercury;
1 " " " carbonate of ammonia (crystals):
1 1-oz. " " oxalic acid (crystals);
1 " " " phosphate of soda (crystals);
Slips of blue litmus paper;
" " red litmus paper;
1 4-oz. flat-bottom clear-glass bottle;
A wooden test-tube holder;
1 small spirit-lamp;
½ pint of alcohol;
A test-tube brush;
½ dozen test-tubes.

These can be supplied by any chemist.

Take any clean bottle and fill it with the water you desire to test, and proceed as follows:

To see whether the Water is Hard or Soft.—Take a clean test-tube and pour into it about three quarters of an inch in depth of the soap solution; then pour into it three or four drops, only, of the water; if it becomes milky or curdy, the water is hard.

To see if the Water is Alkaline or Acid.—Dip into a test-tube half filled with water a strip of red litmus paper; if it does not turn blue, the water is not alkaline. Now dip a strip of blue litmus-paper into the water; if it does not turn red, the water is not acid.

To see if there is Carbonic Acid.—Fill about three quarters of an inch of water in a test-tube and then pour in just as much lime-water; if there is carbonic acid, the water will become milky, and on adding a little hydrochloric acid the water will become clear again.

Test for Sulphate of Lime (*Gypsum*).—Fill in the water to the depth of 1½ inches in a test-tube, and then add a little chloride of barium; if a white precipitate is formed, and it will not re-dissolve when you add a little nitric acid, sulphate of lime is present.

Test for Magnesia.—Fill a test-tube about one fourth or one third full of water; hold it with tube-holder, and bring it to a

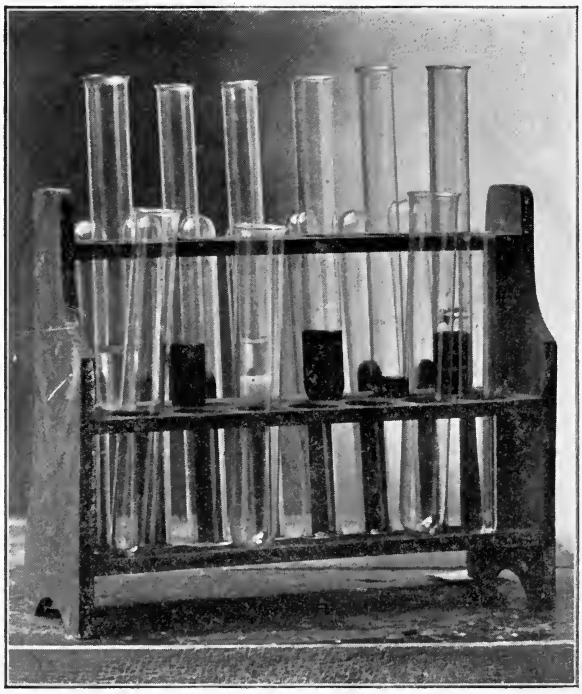

FIG. 1*b*.—Test-tubes.

boil over the spirit-lamp; then add the point of a knife full of carbonate of ammonia, and a very little phosphate of soda; if magnesia is present, it will form a white precipitate; but as it may not do so at once, it is best to set it one side for a few moments.

Test for Lead.—Fill a test-tube one fourth full of the water, and add one or two drops, only, of tincture of cochineal. If there is

only a trace of lead in the water, it will be colored blue instead of pink.

Test for Copper.—Add to some water in a test-tube a little filing dust of soft iron, and a few drops of chloride of ammonium; a blue coloration denotes the presence of copper.

Test for Iron.—To some water in a test-tube add one drop of ferrocyanide: it will color it blue if iron is present.

Test for Sulphur Combinations.—Pour enough mercury into a small glass bottle with a flat bottom to cover it, then pour in water enough to fill it for a depth of half an inch or more, stopper the bottle and let it stand a few hours. If the mercury assumes a darker surface, and upon shaking separates into a dark powder, the water contains sulphur combinations.

General Instructions.—Remember to rinse a test-tube out thoroughly before using with the water that you are about to test, and after making one test rinse out the tube thoroughly in the water, using the tube-brush if necessary.

The soap solution can be prepared by putting some fine scrapings of white curd soap (from an apothecary) into a bottle and pouring alcohol upon it, then cork the bottle and set it one side, shaking it often for a few days until it is all dissolved, then add a little more soap, and if you find you have too much, add a little alcohol, so as to just dissolve it.

Lime-water can be prepared by slaking a small lump of freshly burned lime with half its weight of water in a vegetable-dish; then take some of the slaked lime and put it in a bottle with some cold distilled water (which can be obtained by condensing steam), and shaking it occasionally; then let the undissolved portion subside, draw off most of the clear liquid, and keep it tightly stoppered in a clean bottle.

Note.—Lime-water shaken up with linseed-oil in a bottle forms a yellowish, creamy substance, which is a very soothing and cooling application in case of severe burns and scalds.

Professor Hayes, in speaking of the deposits in tubes and flues, says:

" They are of two kinds, both of which are capable of corroding the iron rapidly, especially when the boilers are heated and in operation. The most common one consists of soot (nearly pure carbon) saturated with pyroligneous acid, and contains a large

proportion of iron if the deposit is an old one, or very little of it if it has been recently formed. The other has a basis of soot and fine coal-ashes (silicate of alumina) filled with sulphur acids, and containing more or less iron, the quantity depending on the age of the deposit. The pyroligneous deposits are always occasioned by want of judgment in kindling and managing the fires. The boilers being cold, the fires are generally started with wood; pyroligneous acid then distils over into the tubes, and, collecting with the soot already there from the first kindling fires, forms the nucleus for the deposits, which soon become permanent and more dangerous every time wood is used in the furnace afterwards.

"The sulphuric-acid deposits derive their acids from the coal used, but the basis material holding these acids is at first occasioned by cleaning or shaking the grates soon after adding fresh charges of coal. Fine ashes are thus driven into the flues at the opportune moment for them to become absorbents for the sulphur compounds distilling from the coals, and the corrosion of the iron follows rapidly after the formation of these deposits."

It is well to remark that the above-mentioned deposits form a very hard incrustation, though of but little thickness generally, and that they are very bad conductors of heat; therefore their removal is necessary.*

Testing Feed-water.—In Holland factories and on Holland steamers, when sodium carbonate is employed to prevent scale, they use † what is known as the "Erfmann Boiler-water Controller" to test the water and tell them how much carbonate of soda to put in the boiler.

As will be seen from the accompanying cuts, the apparatus consists of two graduated vessels, marked respectively 1 and 2 (Fig. 2 with a pipette or inner tube), and a base containing a filter, fitted in a case, Fig. 3. The case also contains three drop-bottles (two for chemicals and one for boiler-water), a box of filter-papers, and a cleaning-brush, compactly fitted for use on steamships.

On opening the case the directions for use are found inside of the cover. By following these failure is said to be impossible. The base of the apparatus slides into two dovetail catches and is

* From Tower's Guide-posts on the Engineer's Journey.

† U. S. Consular Reports, No. 1699.

easily removable. All the other parts are provided with proper receptacles to insure safety and to minimize the risk of breakage.

Bottle 1 contains a yellow liquid, and bottle 2 a colorless liquid. The bottles are made in such a way that the flow of liquid can be regulated to a nicety by the finger-tip on the air-inlet. To

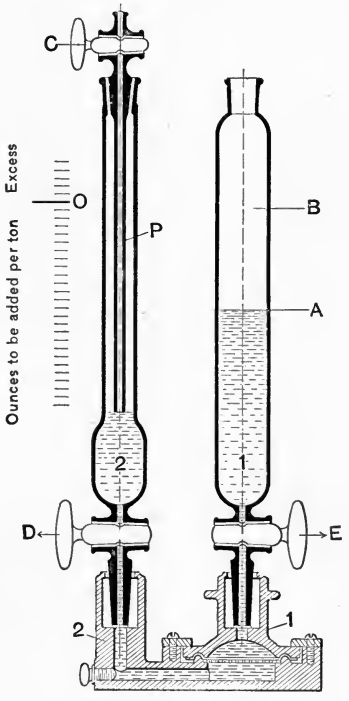

FIG. 2.—Controlling Apparatus.

operate the apparatus one has only to observe the directions, as follows:

Place a piece of filter-paper in the filter (above the perforated plate, to avoid tearing). Vessel 1 is then placed in position with cock closed, and filled to mark *A* with hot water taken from the boiler. The yellow liquid is then added to the height of mark *B* and the contents shaken to mix them properly. Next, vessel 2 is placed in position, with inner tube *P* inserted, whereupon all cocks are opened. The liquid in vessel 1 (which has become thick) passes through the filter and rises into vessel 2 in a clear state.

Only a certain quantity can rise, and, as it would be unsatisfactory to leave this to the manipulator, the pipette, or inner tube *P*, is used to obtain the exact quantity. When the fluid has reached the maximum level in vessel 2 (that is, when it has risen in the pipette *P*) all the cocks are closed and the pipette and its contents removed. The remainder is the proper quantity for testing.

Take vessel 2, and from bottle 2 add the colorless liquid drop by drop until a change of color from yellow to red is observed. When the vessel is shaken this red tinge will disappear. The

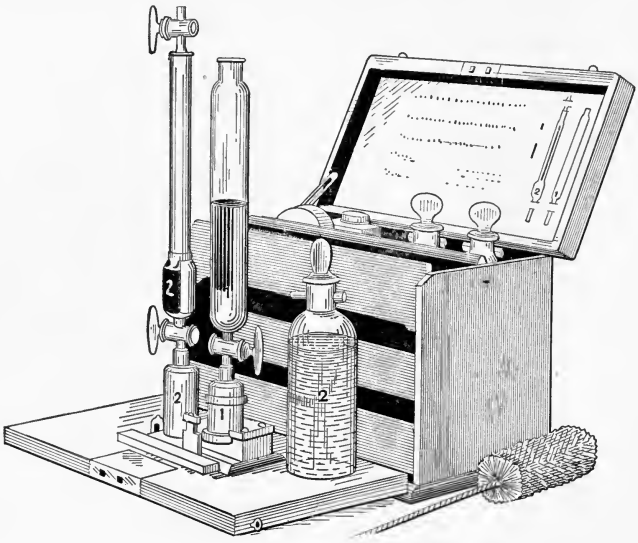

FIG. 3.—Case of Apparatus.

process of adding drops should, however, be continued until the red tinge remains permanent after shaking the mixture.

Result.—The level at which the reddish fluid stands indicates on the graduated scale as follows:

A. By the number of degrees (or lines) below zero the quantity in ounces of soda-ash required to be added daily for each ton of boiler capacity, each line indicating one ounce per ton.

B. By the number of degrees above zero the presence already of an excess of soda. In this event the quantity of soda added daily must be decreased accordingly.

C. If the level stands at zero, then the water is not corrosive

or liable to cause incrustation and the daily additions are correct in quantity. By boiler capacity is understood the normal quantity of water that is always kept in the boiler.

How to Add Soda.—The first time the boiler-water is tested or examined it naturally contains a great deal in the shape of harmful elements, especially if the boiler has been in use for a long period. If when tested the controller indicates 5 ounces per ton (which means that the boiler-water is of a bad nature), then, if dealing with a boiler which holds 16 tons of water, it is necessary to put into the boiler at once 16 times 5 ounces (5 pounds) of soda. This will make the water in the boiler harmless.

When the boiler is fed continuously it may, upon testing, be found the following day that a need of 4 ounces per ton is indicated, which means that since the 5 pounds were added such a quantity of impure elements has entered the boiler that 16 times 4 ounces (4 pounds) of soda is required to neutralize them. Then 4 pounds is added at once, and as new water is being fed, another 4 pounds should be added during the time the boiler is in use that day. The latter quantity, however, should be dissolved in a tank or bucket to enable the boiler to take it up during the working-day. If on the third day the controller indicates zero, the adding of 4 pounds of soda per working-day may be continued, and it will after that be sufficient to test the boiler-water once or twice a week.

As stated before, the quantity of carbonate of soda required for one work-day is dissolved in a small tank or bucket which can be connected by means of a cock and tube to the feed-pump suction-pipe, as shown at *A* (Fig. 4), regulating it in such a way that it will take up the contents of the tank gradually during the time the boiler is in use each day. When several boilers used for different purposes are fed by one pump, then the soda must be added direct to each boiler. This may be done by means of a soda-cup, as in *B*. The soda-cup may, however, be placed right on the boiler *C*.

How to Blow Off Effectively.—The soda-ash having caused the impurities to sink to the bottom of the boiler in the form of a soft mud, this may be removed by occasionally blowing off. This should be done when the boiler is not in use—for instance, in the morning before firing up, and even then with the blow-off cock partially opened. It is not necessary to blow off longer

than is required to lower the water-level about 2 inches, and it is useless to blow off under high pressure, as the water circulation would keep the mud stirring and only a small portion of it would be removed. Sea-going steamers can therefore only rarely blow off; but, owing to the use of condensers, the boilers on such steamers do not require it so frequently. In their case corrosion is feared more than incrustation.

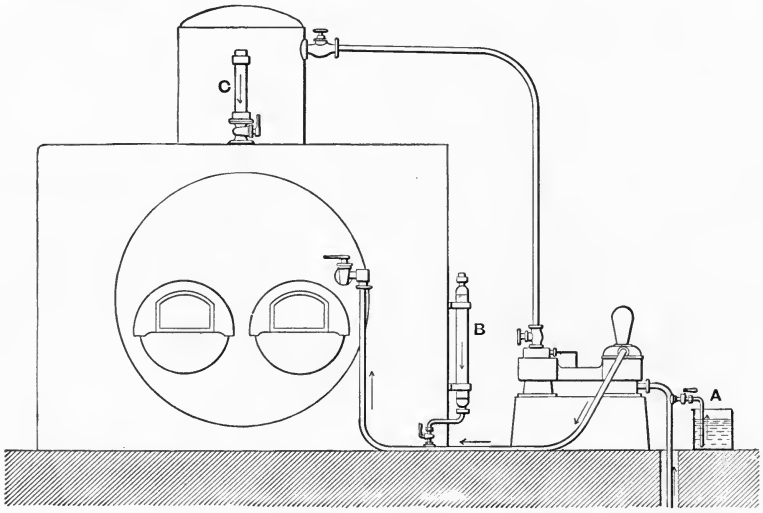

FIG. 4.—Apparatus attached to Boiler.

It is claimed that the apparatus is a remarkable labor-saver, and the fact that the Holland-American Steamship Company of Rotterdam, Holland, used to employ thirty men to clean out the boilers after every home trip of one of their steamers across the Atlantic, besides laying up their steamers once in three years for two months for a thorough cleaning out, while at present, with the aid of the apparatus described, the boilers are cleaned out by means of a hose in a couple of hours, seems to warrant the claim.

Pittsburgh Testing Laboratory Method for Calculation of Chemicals Required for Water-softening, or Neutralization of Acid Waters.*—Basis: Add one equivalent of lime for free carbon

* This and Archbutt's Method on the next page are given here by permission of James O. Handy, Chief Chemist of the Pittsburgh Testing Laboratory, and are from a paper by him read before the Engineers' Society of Western Pennsylvania.

dioxide, insoluble lime, insoluble magnesia, soluble magnesia, acid iron salts, and free acid. Insoluble magnesia requires two equivalents of lime.

Add soda enough for soluble lime and soluble magnesia and free acid, including acid iron salts.

Iron present as carbonate is removed by the addition of an equivalent of lime.

Parts per 100,000.		Pounds for 1000 U. S. Gallons.
CaO, insoluble (i.e., as carbonate)	× .0925	= commercial lime, 90% CaO
MgO, insoluble (i.e., as carbonate)	× .26	= " " " "
MgO, soluble (i.e., as sulphate) MgO, soluble (i.e., as chloride) MgO, soluble (i.e., as nitrate)	× .13	= " " " "
Acid, free (calculated as H_2SO_4)	× .053	= " " " "
CO_2, free	× .118	= " " " "
Fe (as carbonate)	× .093	= " " " "
CaO, soluble	× .166	= Soda-ash, 95% Na_2CO_3
MgO, soluble	× .233	= " " "
Acid, free	× .095	= " " "

At 15° C., saturated lime-water = 1.3 g. per liter.

At 15° C., saturated lime-water = 1.083 lbs. per 100 gallons.

The solubility of lime in water varies slightly.

ARCHBUTT'S METHOD FOR CALCULATION OF CHEMICALS REQUIRED FOR WATER-SOFTENING.*—As much sodium carbonate is dissolved n a little water as is equivalent to the total lime and magnesia, deducting as much as is equivalent to the total alkalinity of the water.

Lime-water enough is added to give a straw-color with silver nitrate, and then as much more as is equivalent to the magnesia present. This would apparently lead to the same results as would be obtained by our method of calculation. We have not tested it.

Returning to a further consideration of the method in which it is best to state the results of chemical analyses of water, it may be admitted that the simple statement of basic and acid radicals actually found will be safest and wisest in some cases.

In a very great number of instances, however, the client desires to have the analysis show the most probable combination of bases and acids. He wishes to know what salts are in the water, so that its medicinal or technical uses may be intelligently understood.

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* See foot-note p. 24.

For this reason it is desirable that chemists should get together and agree upon a method of expressing results.

Cairns, "Quantitative Analysis," 1888, p. 182, follows this plan, which he says meets most cases: Combine the sodium with chlorine as sodium chloride, and the potassium with sulphuric acid as potassium sulphate. Should there be any more sodium than chlorine, and more sulphuric acid than is required by potassium, combine the excess with sodium, and if there is more sodium left, combine it with carbonic acid.

Should there be more than enough sulphuric acid for both sodium and potassium, combine excess first with calcium as calcium sulphate, and next with magnesia as magnesium sulphate.

If chlorine is more than enough to satisfy sodium, combine it with potassium if sulphuric acid was not sufficient. If chlorine is still in excess, combine it with magnesium and then with calcium. Calculate all calcium and magnesium, not combined with chlorine, and sulphuric acid, as carbonates.

This method may be criticised in that it makes no provision for nitric acid if present, and that it does not take advantage of the absolute knowledge which may be gained by analysis, as to the amounts of calcium and magnesium present as carbonates. The method is based on Fresenius's earlier recommendations. In the latest * edition of Fresenius the following example of a water-analysis calculation is given. Mr. Handy determines the calcium precipitated by boiling, and calculates it to carbonate. Beyond that he attempts to combine acids and bases according to relative affinities and solubilities:

1. Barium calculated to sulphate of barium.
2. Strontium calculated to sulphate of strontium.
3. Residual sulphuric acid calculated to calcium sulphate.
4. Bromine calculated to magnesium bromide.
5. Iodine calculated to magnesium iodide.
6. Calcium not precipitated by boiling, and not already figured to sulphate, is calculated to chloride of calcium.
7. Potassium calculated to chloride of potassium.
8. Lithium calculated to chloride of lithium.

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* "Traité de l'Analyse Quantitative," R. Fresenius, 7th French from 6th German edition, 1900.

9. Ammonia calculated to chloride of ammonium.

10. Sodium calculated to chloride of sodium.

11. Residual chlorine calculated to magnesium chloride.

12. Phosphoric anhydride calculated to phosphate of calcium.

13. The calcium found in the precipitate on boiling, minus the amount required by phosphoric acid, is calculated to carbonate.

14. The magnesium not calculated to bromide, iodide, or chloride is figured to carbonate.

15. The iron found is calculated to carbonate.

16. The manganese found is calculated to carbonate.

17. The silica found is calculated as silica.

18. The free carbonic acid is calculated by deducting from the total the amount required by the lime, magnesia, and iron to form bicarbonates. In alkaline waters the phosphoric acid is calculated to phosphate of alumina. In saline waters it is figured as phosphate of calcium.

The scheme given above was used in connection with a mineral-water analysis. No provision is made for nitric anhydride.

Fresenius's General Rule for Water-analysis Calculation.—This is supposed to apply to technical analyses where the rarer elements are not determined, and is given in the 1900 edtion.

If the water is alkaline, all of the calcium and magnesium present are calculated as carbonates. Otherwise proceed as follows:

1. Combine all chlorine with sodium.

2. Combine excess chlorine with calcium.

3. Combine sulphuric acid with calcium.

4. Combine nitric acid with ammonium, and then with calcium or magnesium, if necessary.

5. The remaining lime and magnesia are calculated as carbonates.

This rule is very incomplete, in that it does not provide for the disposal of the sodium which might be in excess of the chlorine. It is also silent on the disposition of sulphuric acid in excess of the amount required by calcium, and of nitric acid in excess of the amounts required by the bases enumerated. The first illustration is much more complete.

There seems to be a feeling among the followers of Fresenius that in general the sodium and potassium should be the first bases to be provided for, and they are generally given the chlorine or sulphuric acid, or both if necessary.

The method of analysis used in the Kennicott laboratories is shown on a chart recently sent out for criticism, and differs from plans in general use, in that it provides for the determination of the amount of calcium sulphate actually present. This is accomplished by the use of alcohol of 0.92 specific gravity as a solvent for treating the dry residue. Silica, carbonates of lime and magnesia, and sulphate of lime are insoluble in this menstruum. They are afterwards separated, the determination of sulphuric anhydride being the index to the amount of calcium present as sulphate.

This removes one more arbitrary step from water-analysis calculation, but it is accomplished at the expense of some time and considerable alcohol. It does not affect water-softening calculations at all, but is designed to give certain information regarding the most important scale-forming compound which occurs in waters. The actual value of the alcohol used for each analysis would be from six to ten cents, which is not so serious a matter as would at first appear.

The fact that three hours are required for the extraction indicates that sulphate of soda and the other soluble salts do not dissolve rapidly, and errors due to incomplete extraction would have to be guarded against by tests, as suggested.

ORDER IN WHICH BASES ARE APPORTIONED TO ACIDS BY SEVERAL ANALYSTS.

		Sulphuric Acid.	Chlorine.	Nitric Acid.
Cairns	1.	Potassium	Sodium	
	2.	Sodium	Potassium	
	3.	Calcium	Magnesium	
	4.	Magnesium	Calcium	
Fresenius	1.	Barium	Calcium	
	2.	Strontium	Potassium	
	3.	Calcium	Sodium	
	4.	.....	Magnesium	
Pittsburgh Testing Laboratory	1.	Calcium	Calcium	Calcium
	2.	Magnesium	Magnesium	Magnesium
	3.	Sodium	Sodium	Sodium
	4.	Potassium	Potassium	Potassium
Kennicott	1.	Calcium *	Calcium	
	2.	Magnesium †	Magnesium	
	3.	Sodium	Sodium	

* Calcium calculated from sulphate insoluble in alcohol.

† Magnesium figured to sulphate is the amount left over after figuring the magnesium combined with chlorine.

The scheme makes no provision for calculation of nitrates, but it seems to the writer to be commendable in other respects. If the plan could be elaborated further to allow discrimination between magnesium chloride, sulphate, and nitrate, nothing would be left to the analyst's judgment. This, however, is hardly to be hoped for, and it is therefore desirable to have the necessarily arbitrary calculations all made by the same method.

For technical work direct determinations of sodium and potassium are not usually made. The residual acids not required for the bases found are calculated to sodium salts.

Analysis of Water.—The following table gives the results of tests made by Prof. C. F. Chandler of waters along the line of the New York Central Railroad. (The figures represent grains per U. S. gallon.)

Source.	Corroding Matter.	Incrusting Matter.	Organic Matter.	Total Solids.
Syracuse, Onondaga Creek	3.44	22.58	0.34	26.36
" hydrant	0.38	27.55	trace	27.93
Memphis	0.91	21.68	0.18	22.77
Jordan	1.71	11.47	0.06	13.24
Port Byron	1.08	7.17	1.28	9.53
Savannah	1.35	17.63	1.52	20.50
Clyde, spring	0.77	14.64	2.16	17.58
" river	2.10	14.30	1.88	18.28
Lyons	1.03	11.07	1.00	13.10
Newark	1.17	18.73	2.16	22.07
Palmyra	1.43	33.39	1.46	36.28
Macedon Swamp	0.71	10.53	0.80	12.04
Fairport	3.19	15.06	1.14	19.39
Rochester, N. Street well	7.31	33.26	1.60	42.17
" Genesee River	1.18	10.85	1.64	13.67
" canal, roundhouse	1.11	8.80	1.24	11.15

WATERS AT VARIOUS POINTS IN THE NEW ENGLAND STATES, ANALYZED BY S. DANA HAYES.

(Grains per one U. S. gallon.)

No.	Source.	Mineral Matter.	Organic Matter.	Total Solids.
	MAINE.			
1	Pure spring, near Auburn	0.85	0.13	0.98
2	Spring on Cape Elizabeth	7.40	2.21	9.61
3	Wells in Portland (av of four)	13.35	5.13	18.48
	NEW HAMPSHIRE.			
4	Merrimac River, at Manchester (drainage)	2.96	2.60	5.56
5	Merrimac River, at Lowell, Mass.	1.80	0.11	1.91
6	Massabeesic Lake, near Manchester	1.16	1.66	2.82
7	Hotel well, on Rye Beach	6.08	2.43	8.51
	VERMONT.			
8	Mineral Springs, near St. Albans (av of seven)	15.24	1.25	16.49
9	" " at Guilford (chalybeate)	25.27	1.65	26.92
10	" " at Brunswick	77.79	2.33	80.12
11	" " at Danby	7.19	0.91	8.10
	MASSACHUSETTS.			
12	Cochituate, Boston, February, 1871	2.37	0.83	3.20
13	Mystic, Charlestown, February, 1871	3.96	1.72	5.68
14	Jamaica Pond, Roxbury, 1867	2.41	1.36	3.77
15	Connecticut River, at Holyoke	1.81	1.39	3.20
16	Saugus River, Lynn	3.12	2.40	5.52
17	Flax Pond, Lynn (drainage)	2.24	1.84	4.08
18	Horn Pond, Woburn	3.85	1.59	5.44
19	Locomotive supply, Taunton	4.37	2.03	6.40
20	Artesian well, Dedham	4.08	1.11	5.19
21	Wells in Woburn (av of four)	51.52	4.60	56.12
22	Wells in Lynn (av. of six)	19.27	4.23	23.50
23	Old artesian well, Boston (reopened 1871)	54.35	1.85	56.20
24	Well on Cape Cod	10.01	2.41	12.42
25	Brewery spring, Boston	13.68	1.68	15.36

Mr. J. T. Fennell says, leaving Philadelphia, the farther west you go the worse boiler-water gets. Pittsburg water is rather bad; Columbus, O., is worse, but the worst he has found is at Junction City, Kan. At Newton, Kan., the water is very good, the boilers looking as though newly whitewashed, which is about as thick as scale gets at this place.

Birmingham, Ala., water is bad—makes lots of scale—while Atlanta, Ga., water is excellent, where light scale and some red mud is found when examining boilers.

Artesian well-water at Atlantic City and Camden, N. J., is good, especially at Camden, where there are some boilers, installed in 1868, which are nearly as good as when new as far as appearances are concerned. These boilers are well cared for and are *never blown out while they are hot.*

The well-water in Philadelphia, Pa., is very bad for boilers, while at Brandywine Summit, Pa., it is fairly good and leaves a chalk-like deposit.

Analysis of Sea-water.

(Grains per gallon.)

Carbonate of lime	9.75	grains
Sulphate of lime	114.36	"
" " magnesium	134.86	"
Chloride of "	244.46	"
" " sodium	1706.00	"
Total	2209.47	grains

Sea-water, according to one authority, contains from 32 to 38 parts of salt, or sodium chloride, per 1000 parts of water.

Water Analysis.

Mineral water from a well about 60 feet deep at Carrizo Springs, Texas, has been analyzed with these results in grains per U. S. gallon:

Total mineral matter	1306.18
Magnesium sulphate	231.00
Sodium sulphate	390.00
" chloride	467.00
" bicarbonate	80.30
Calcium	130.40
Potassium chloride	5.50
Soluble silica	0.71

Table of Water Analyses.

Grains per U. S. Gallon of 231 Cubic Inches.

Where From.	Lime and Magnesia Carbonates.	Lime and Magnesia Sulphates.	Sodium Chloride (Salt).	Iron Oxide, Carb. Sulph., etc.	Volatile and Organic Matter.	Total Solids in Grains.
Buffalo, N. Y., Lake Erie	5.66	3.32	0.58	....	0.18	9.74
Pittsburgh, Allegheny River	0.37	3.78	0.58	0.37	1.50	6.60
" Monongahela River	1.06	5.12	0.64	0.78	3.20	10.80
" Pa., artesian well	23.45	5.71	18.41	1.04	0.82	49.43
Milwaukee, Wisconsin River	6.23	4.67	1.76	20.14	6.50	39.30
Galveston, Texas, 1	13.68	13.52	326.64	Trace	Trace	353.84
" " 2	21.79	29.15	398.99	....	4.00	453.95
Columbus, Ohio	20.76	11.74	7.02	0.58	6.50	46.60
Washington, D. C., city supply	2.87	3.27	Trace	0.36	2.10	8.60
Baltimore, Md., city supply	2.77	0.65	Trace	0.10	3.80	7.30
Sioux City, Ia., city supply	19.76	1.24	1.17	1.03	4.40	27.60
Los Angeles, Cal., 1	10.12	5.84	3.51	2.63	4.10	26.20
" " " 2	3.72	12.59	....	0.76	6.00	23.07
Bay City, Michigan, Bay	8.47	10.36	20.48	1.15	8.74	49.20
" " " River	4.84	33.66	126.78	3.00	10.92	179.20
Cincinnati, Ohio River	3.88	0.78	1.79	....	Trace	6.73
Watertown, Conn	1.47	4.51	1.76	Trace	1.78	9.52
Fort Wayne, Ind	8.78	6.22	3.51	1.59	10.98	31.08
Wilmington, Del	10.04	6.02	4.29	8.48	6.17	35.00
Wichita, Kansas	14.14	25.91	24.34	....	2.00	66.39
Springfield, Ill., 1	12.99	7.40	1.97	2.19	8.62	33.17
" " 2	5.47	4.31	1.56	4.28	5.83	21.45
Hillsboro, Ill	14.56	2.97	2.39	1.63	Trace	21.55
Pueblo, Colo	4.32	16.15	1.20	1.97	5.12	28.76
Long Island City, L. I	4.0	28.0	16.0	....	1.0	39.0
Mississippi River above Missouri River	8.24	1.02	0.50	....	5.25	15.01
Mississippi River below mouth of Missouri River	10.64	7.41	1.36	1.22	15.86	36.49
Mississippi River at St. Louis, W. W	9.64	6.94	1.54	1.57	9.85	29.54
Hudson River above Poughkeepsie, N. Y.	1.06	....	0.11	10.76	0.77	12.70
Croton River above Croton Dam, N. Y.	4.57	0.16	0.40	1.92	0.67	7.72
Croton River water from service-pipes in New York City	2.36	....	....	1.36	....	3.72
Schuylkill River above Philadelphia, Pa.	2.16	0.29	0.49	1.30	....	4.24

TABLE OF WATER ANALYSES FURNISHED BY THE INDUSTRIAL WATER COMPANY.

	Penn. Lines, Well, Crestline, O.	Penn. Lines, Pond, Crestline, O.	Penn. Lines, Spring, Crestline, O.	Central City Ice, Macon, Ga.	Houston Coal & Coke Co., Elkhorn, W. Va.	C., C., C. & St. L., Columbus, O.	C. C., C. & St. L., Springfield, O.	M., K. & T., Denison, Tex.	Penn. Lines, Shops, Columbus, O. (Well-water.)	Penn. Lines, City Water, Columbus, O.	Penn. Lines, Cambridge City.	Penn. Lines, Indianapolis, Ind.	N. Y. C. & H. R., Dewitt, N. Y.	Penn. Lines, Bradford, O.	Penn. Lines, Fletcher, O.	Penn. Lines, Unionville, O.	Penn. Lines, Middlepoint, O.	Farnham, Utah.
Total residue..	75.39	16.70	27.85	10.12	34.01	31.87	28.58	42.29	153.15	39.35	20.00	23.72	29.65	29.53	26.22	24.49	63.52	386.7
Vol. and organic.....	——	——	——	1.23	——	——	——	——	24.96	6.81	7.32	5.18	——	2.64	4.48	5.32	7.46	43.7
SiO_2.....	0.40	0.75	0.94	0.35	0.76	0.47	0.44	0.98	0.52	0.56	0.33	0.47	0.33	0.47	0.70	0.16	0.65	0.6
Al_2O_3 ..... } Fe_2O_3 ..... }	0.12	0.14	0.16	0.16	0.00	0.17	0.09	0.14	0.23	0.12	0.16	0.14	0.14	0.09	0.23	0.26	0.19	2.0
$FeCO_3$.....	0.00	0.00	0.00	0.00	2.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
$CaCO_3$.....	0.92	2.75	13.80	0.00	3.45	11.50	15.13	24.58	17.25	20.25	11.28	12.50	10.50	15.49	12.08	10.07	16.50	26.1
$CaSO_4$.....	0.00	2.22	0.95	0.15	10.88	5.37	0.00	0.00	61.54	0.00	0.00	0.00	6.73	0.00	0.00	0.00	16.08	50.8
$MgCO_3$.....	0.69	0.00	0.00	0.00	0.00	0.00	0.25	0.56	0.00	2.52	4.38	3.36	0.00	3.79	5.60	2.25	0.00	0.0
$MgSO_4$.....	0.00	1.50	8.22	0.00	4.74	8.49	9.39	0.33	40.32	9.93	1.83	2.58	6.69	5.37	1.86	7.32	19.65	93.0
$MgCl_2$.....	0.00	1.07	0.33	0.76	1.74	0.85	0.56	4.80	2.41	0.53	0.54	1.19	0.74	0.67	0.54	1.07	1.61	23.6
Na_2CO_3.....	56.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
Na_2SO_4.....	1.03	2.06	1.42	0.00	8.52	0.18	0.00	8.13	16.54	2.41	0.00	1.88	1.92	1.42	3.09	1.07	3.76	140.6
NaCl.....	14.03	0.00	0.00	5.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
Free CO_2.....	0.66	1.04	1.80	1.12	1.60	——	——	——	1.28	2.92	0.84	0.88	0.40	——	——	——	——	——
Scale-forming solids.....	2.13	8.43	24.40	1.95	23.73	26.85	25.86	31.39	122.28	33.91	18.52	20.24	25.13	25.88	21.01	21.13	54.68	196.1
$CaCl_2$.....	0.00	0.00	0.00	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
$NaNO_3$.....	——	——	——	2.22	——	——	——	——	——	——	——	——	——	——	——	——	——	——

Where the dash appears in the table it signifies that the compound in that instance was undetermined.

Water Analyses.

[W. B. Scaife & Sons Co.]

Impurities, Expressed in Grains, per U. S. Gallon (about 58,000 Grains).	Carbonates.	Sulphates and Other Solids.	Total Solids.
Akron, Ohio.	9.01	19.79	28.80
Albany, N. Y. (average, 3 wells)	.....	.....	48.69
Ashtabula, Ohio.	5.65	3.95	9.60
Austin, Texas.	9.80	13.68	23.48
Baltimore, Md. (city supply).	2.77	4.53	7.30
Bay City, Mich. (bay)	8.47	40.73	49.20
" " " (river)	4.84	173.36	179.20
Beaufort, S. C.	31.40	23.20	54.60
Bethlehem, Pa.	1.18	4.22	5.40
Benwood, W. Va.	3.64	9.37	13.01
Binghamton, N. Y.	3.62	3.08	6.70
Boston, Mass. (average, 3 wells)	.....	.....	44.46
Boulder, Col.	5.65	7.05	12.70
Bridgeport, Conn.	3.90	16.26	20.16
Brooklyn, N. Y. (average, well).	.....	.....	48.83
Buffalo, N. Y. (Lake Erie)	5.66	4.08	9.74
" " (river).	6.74	6.78	13.52
" " (average, 3 wells)	33.71	134.12	167.83
Canton, Ohio.	1.85	26.05	27.90
Chicago, Ills. (average, 5 wells)	32.16	55.92	88.08
Chicago Heights, Ills.	1.39	0.81	2.20
Cincinnati, Ohio (Ohio River).	3.88	3.85	6.73
Clarksville, Tenn.	12.48	11.77	24.25
Columbus, Ohio.	20.76	25.84	46.60
Connecticut River (above Springfield).	1.57	4.44	6.01
Dallas, Tex.	19.82	53.48	73.30
Dayton, Ohio (well).	.....	.....	56.50
Decatur, Ills.	34.48	4.27	38.75
Detroit, Mich. (well)	.....	.....	116.46
Dunnellon, Fla.	8.39	9.51	17.90
Easton, Pa.	1.45	7.05	8.50
Elwood, Ind. (average, 2 wells).	17.61	4.73	22.34
Ensley, Ala. (village creek).	9.43	8.42	17.83
Fall River, Mass. (average, 17 wells)	.....	.....	36.12
Ft. Wayne, Ind. (river-water).	16.15	28.70	44.85
" " " (well)	14.37	47.43	61.80
Galveston, Tex.	22.79	381.20	403.99
Grand Rapids, Mich. (Grand River)	9.02	22.22	31.24
Hamilton, Ontario.	6.02	5.18	11.20
Harrisburg, Pa.	.....	.....	12.13
Hartford, Conn. (average, 5 wells)	.....	.....	47.21
Hartford City, Ind.	16.11	22.45	38.56
Harvey, Ills.	14.85	71.12	85.97
Hillsboro, Ills.	14.56	6.99	21.55
Hudson River (above Poughkeepsie).	3.19	9.51	12.70
Hull, Fla.	1.38	6.82	8.20
Indianapolis, Ind. (creek)	2.17	0.33	2.50
" " (well)	1.57	36.85	38.42
Ivorydale, Ohio.	16.90	3.68	20 58
Joliet, Ills. (well)	15.67	39.91	55.58

WATER ANALYSES—*Continued.*

Impurities, Expressed in Grains, per U. S. Gallon (about 58,000 Grains).	Carbonates.	Sulphates and Other Solids.	Total Solids.
Joplin, Mo.	9.09	7.71	16.80
Junction City, Kans.	20.82	9.43	30.25
Kansas City, Mo.	10.50	5.20	15.70
Kent, Ohio.	9.86	4.34	14.20
Lebanon, Pa.	3.60	3.59	7.19
Lockport, N. Y	6.61	5.60	12.21
Long Island City, N. Y.	5.40	33.90	39.30
Lorain, Ohio, Black River.	4.86	9.86	14.72
Los Angeles, Cal.	3.72	19.35	23.07
Lowell, Mass. (average, 15 wells).	.....	.....	39.33
Lynn, Mass. (Saugus River).	1.81	4.81	6.62
" " (average, 2 wells).	.....	.....	34.19
Massillon, Ohio (river-water).	.....	.....	35.28
Milwaukee, Wis. (lake-water)	4.50	3.67	8.17
" " (Wisconsin River).	6.23	33.07	39.30
Mississippi River (above Missouri River)	8.24	7.77	15.01
" " (below " ")	9.64	19.90	29.54
Missouri River (above mouth)	10.07	25.42	35.49
Muncie, Ind.	20.30	14.20	34.50
Nebraska City, Neb. (Missouri River).	17.85	39.84	47.69
Newark, N. J.	19.82	26.22	46.04
New York, N. Y. (city supply).	2.36	1.36	3.72
" " " (average, 4 wells).	.....	.....	58.07
Norfolk, Va.	1.14	9.76	10.90
Omaha, Neb. (well).	14.43	59.22	73.65
Oswego, N. Y. (well).	10.93	.....	52.10
Passaic, N. J.	5.70	55.20	60.90
Paterson, N. J.	4.88	8.66	13.54
Piqua, Ohio.	18.80	6.64	25.44
Pittsburgh, Pa. (Allegheny River).	1.56	10.51	12.07
" " (Monongahela River).	1.08	9.72	10.80
" " (average well).	23.70	18.98	42.68
Plainfield, N. J.	4.06	4.64	8.70
Providence, R. I. (average, 24 wells).	.....	.....	33.02
Pueblo, Col.	4.32	24.44	28.76
Pulaski, Va. (city supply).	2.98	2.99	5.97
" " (well).	18.40	3.23	21.63
Rochester, N. Y. (average, 3 wells).	7.32	14.68	22.00
St. Louis, Mo. (average, 3 wells).	16.82	38.15	54.97
San Antonio, Tex.	18.11	12.79	31.90
Sandusky, Ohio.	4.91	12.96	17.87
Schuylkill River (above Philadelphia).	2.16	2.08	4.24
Sharpsburg, Pa. (well-water)	34.62	143.29	177.91
Sharpsville, Pa.	1.99	2.92	4.91
Sheboygan, Mich.	14.44	8.64	23.08
Sherman, Tex.	4.56	8.94	13.50
Sioux City, Iowa.	15.31	42.41	57.72
Springfield, Ills.	12.12	44.25	56.37
" Mass. (Mill River)	2.68	5.54	8.14
" " (average, 4 wells).	.....	.....	13.08
Stockton, Cal. (well)	12.95	80.11	93.06
Streator, Ills.	8.62	21.77	30.39

WATER ANALYSES—*Continued.*

Impurities, Expressed in Grains, per U. S. Gallon (about 58,000 Grains).	Carbonates.	Sulphates and Other Solids.	Total Solids.
Sturgis, Mich.	15.00	8.13	23.13
Sumter, S. C.	0.87	8.33	9.20
Tampa, Fla.	14.66	8.64	23.30
Taunton, Mass. (average, 2 wells)	.....	.....	33.54
Terre Haute, Ind.	11.89	8.25	20.14
Tonawanda, N. Y.	6.16	3.54	9.70
Trenton, N. J.	2.06	3.38	5.44
Tyrone, Pa.	0.93	10.96	11.89
Warners, N. Y. (canal-water)	8.28	12.56	20.84
" " (creek-water)	13.76	35.90	49.68
Warsaw, N. Y.	6.98	67.29	74.27
Washington, D. C. (city supply)	2.87	5.73	8.60
Watertown, Conn.	1.47	8.05	9.52
West Pullman, Ills.	11.89	5.59	17.48
Wichita, Kans.	14.14	42.25	66.39
Wilmington, Del.	6.90	19.60	26.50
Woburn, Mass. (average, 4 wells)	.....	.....	56.12
Youngstown, Ohio.	4.64	14.28	14.90

ANALYSES IN PARTS PER 100,000 OF WATERS GIVING BAD RESULTS FOR STEAM PURPOSES.*

	Bicarbonate of Lime Deposited on Boiling.	Bicarbonate of Magnesia Deposited on Boiling.	Total Lime.	Total Magnesia.	Sulphuric Acid.	Chlorine.	Iron.	Organic Matter.	Alumina.	Chloride of Sodium.	
Feed-water giving											
Scales 2.5-3....	225	19	450	85	219	293					Fischer
" 3 atmos .	88	3	147	22	121	59					"
" 3.5 " .	tr'ce	0	46	9	40	....	See Table D of Boiler Scales*				"
" 3.5 " .	63	39	155	68	89	91					"
" 5 " .	46	0	244	32	232	9					"
" 5-6 " .	tr'ce	0	599	81	306	770					"
Coal-mine wat'r	110	25	119	39	890	590	780	30	640		A. E. Hunt
Salt-well.....	151	38	1.90	48	360	990	38	21	30	13.10	"
Spring.....	75	89	95	120	310	21	75	10	80	36	"
Monongahela River †.....	130	21	161	33	210	38	70				"
do.	80	70	94	81	219	210	90				"
do.	32	82	61	1.04	28	1.90	38				"
Allegheny river near Oil-wr'ks	30	50	41	68	890	42	23				"

* A. I. M. E., Vol. 17, p. 353.
† Taken near discharge-pipes from large manufacturing establishments.

How much of scale-forming impurities may be contained in a feed-water, and it still be called good, depends largely on what the impurities are.

Silvester has given us a classification of this kind:

"Less than 8 grains of incrusting solids per gallon —carbonate of lime, carbonate of magnesia, sulphate of lime, chloride of magnesia, etc.....	Good
8 to 15 grains per gallon.....	Fair
15 to 20 " " "	Poor
20 to 30 " " "	Bad
30 to 40 " " "	Very bad"

TROUBLES DUE TO WATER: PREVENTION AND CURE.

Trouble.	Cause.	Cure.
Incrustation	Sediment, mud, clay, etc.	Filtration. / Blowing-off.
	Readily soluble salts.	Blowing-off.
	Bicarbonate of magnesia, lime, iron	Heating feed and precipitate. / Caustic soda. / Lime. / Magnesia.
	Organic matter	See below.
	Sulphate of lime	Sodium carbonate. / Barium chloride.
Corrosion	Organic matter	Precip. with alum / Precip. with ferric chloride — and filter.
	Grease	Slaked lime / Carbonate of soda — and filter.
	Chloride or sulphate of magnesium	Carbonate of soda.
	Sugars.	
	Acid	Alkali.
	Dissolved carbonic acid and oxygen	Slaked lime. / Caustic soda. / Heating.
	Electrolytic action	Zinc plates.
Priming	Sewage	Precipitate with alum or ferric chloride and filter.
	Alkalies	Heating feed and precipitate.
	Carbonate of soda in large quantities	Barium chloride.

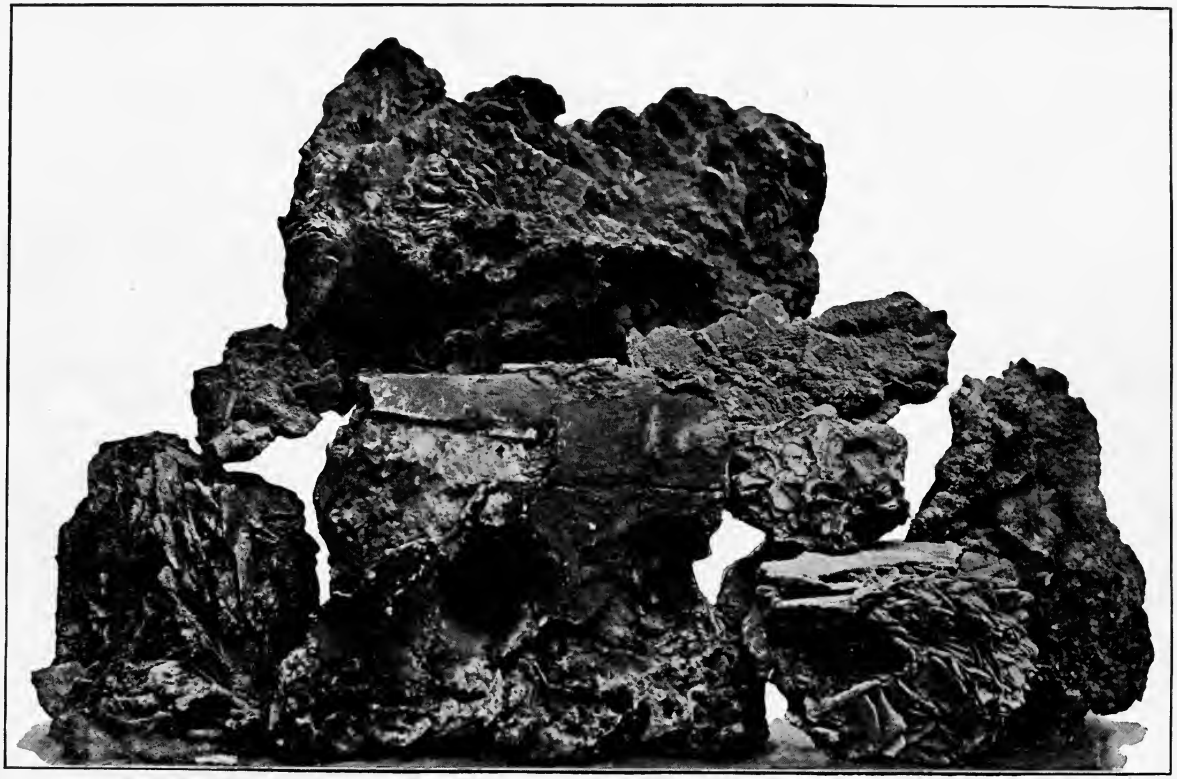

EXHIBIT No. 2.

SCALE BETWEEN SHELL AND TUBES ON SIDE OF BOILER NEAR HEAD.

(Pottstown Cold Storage and Warehouse Co , Pottstown, Pa.)

CHAPTER II.

BOILER-SCALE.

THE hard coating of insoluble materials from boiler feed-waters on the water-heating surface of steam-boilers is called scale; if this deposit anywhere inside the water or steam space is an insoluble powder in form it is called sediment.

Both scale and sediment are poor conductors of heat and also are a cause of overheating of boiler-shells, and wherever there is a deposit of sediment or scale, it is in those places we are most likely to find evidences of corrosion.

One of the principal objections to boiler-scale of ordinary thickness is, that it may cause the metal over the fire to be so highly heated as to cause burning; also leakage of joints and tube-ends and their subsequent corrosion and other forms of rapid deterioration.

So far as evaporative efficiency is concerned, soot on fire-surfaces is often more effectual as a heat retardent than is ordinary scale. Soot is known to be a very good non-conductor of heat.

Fig. 5 shows a bagged and ruptured sheet; the bag to the right having ruptured, the one on the left has not.

In the case of one boiler subjected to inspection for insurance it was found full of scale between the tubes (probably a horizontal return tubular-boiler), necessitating cutting off the front head in order to remove the tubes.

The scale was almost as hard as granite, and had to be broken with a heavy hammer. Five hundred pounds of scale were taken from this boiler.

Mr. James T. Fennell, Chief Inspector for the Maryland Casu-

alty Company, has furnished the writer these interesting items, which are pictured on pages 38, 42, 43 and 45, and facing Chapter II:

Exhibit 1.—C. S. Garratt & Son's Co., Buck Run, Pa., paper-mill. From flange of the rear head, between shell and tubes; was much larger; broken during removal.

(Fidelity & Casualty Co.)

FIG. 5.—A Bagged and Ruptured Sheet.

Exhibit 2.—Pottstown Cold Storage and Warehouse Co., Pottstown, Pa. From flange of the rear head, between the shell and tubes. There was a large quantity of this scale in each of the four corners of the boiler; this sample came from the corner containing the largest quantity.

This was from a boiler supposed to be clean, but the cleanliness was only on the bottom in plain sight, the scale being between the tubes and overhead. The small portions of scale are carried upward by the circulation and come down in the restricted passages between the tubes, and tubes and shell and cement them-

selves to scale already formed at these places, completely shutting off circulation at many points.

Where braces are put in so close that a man cannot get near enough to the boiler-heads to remove the scale there, in time tubes start leaking, and must themselves be removed to get the scale away.

Exhibit 3.—Is from a boiler in John Wanamaker's store, No. 1829 Market Street, Philadelphia, Pa. The scale remaining on the head after tube was removed was chipped off in small pieces, being thoroughly cemented to the head and heads of rivets.

The Vulcanized Rubber Co., at Morrisville, Pa., have also had trouble of this character, and at Mr. Fennell's suggestion removed the bottom tube on each side, tapped the whole, inserted a plug, leaving nothing to catch the scale.

One of the plants of the Cincinnati Gas Light & Coke Co. at Cincinnati, O., having vertical tubular boilers similar to the Manning type, had much trouble with tubes leaking at the lower end, on account of accumulation of scale on tubes and sheet. By removing a tube here and there, and in their places screwing in a brass plug having a square socket for a wrench—a square projection would burn off—it was found thereafter that the furnace crown-sheet and ends of tubes would keep quite clean when boiler was washed out without frequent removal of plugs.

The improved circulation is given as the reason for the conditions then found.

Exhibit 4.—C. S. Garratt & Son's Co., Paper Mill, at Childs, Md. Was taken from a pile of boiler-scale from a number of tubes removed from boilers. While removing these tubes one collapsed.

From these experiences and many others of a like character the designer should give careful consideration to the kind of water that is fed to the boiler, which if bad should only be used in a boiler with free and unrestricted passages, and one from which the scale can be easily removed.

Exhibit 5.—Shows how scale has been thrown up in the drum of a water-tube boiler at the Thirteenth and Mount Vernon Streets power-house of the Philadelphia Rapid Transit Co. The accumulation was almost up to the manhole in the drum.

Stromeyer and Baron say: "Scale does not materially reduce the efficiency of a boiler, but it seriously increases its wear and tear,

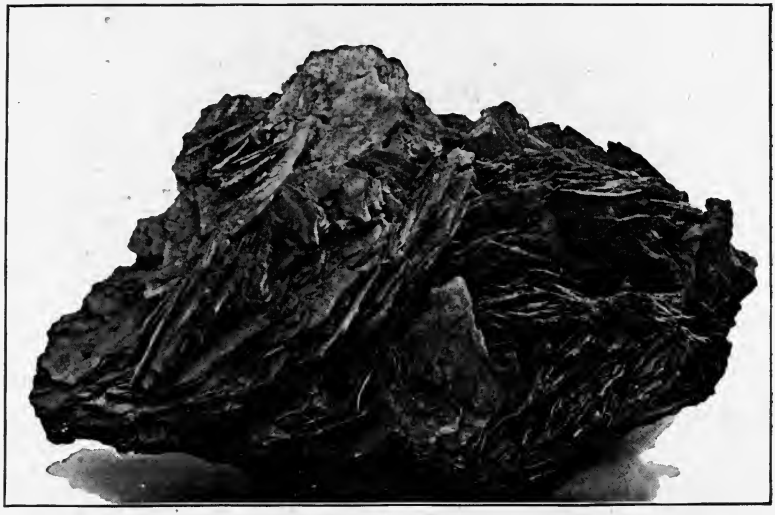

EXHIBIT No. 1.
SCALE BETWEEN SHELL AND TUBES.
(U. S. Garrett & Son Co., Buck Run, Pa.)

EXHIBIT No. 3.
SCALE BETWEEN THE TUBES NEAR BOTTOM OF BOILER, CAUSING TUBE TO LEAK.
(John Wanamaker, 1825-1829 Market St., Philadelphia, Pa.)
Water used—Schuylkill River water.

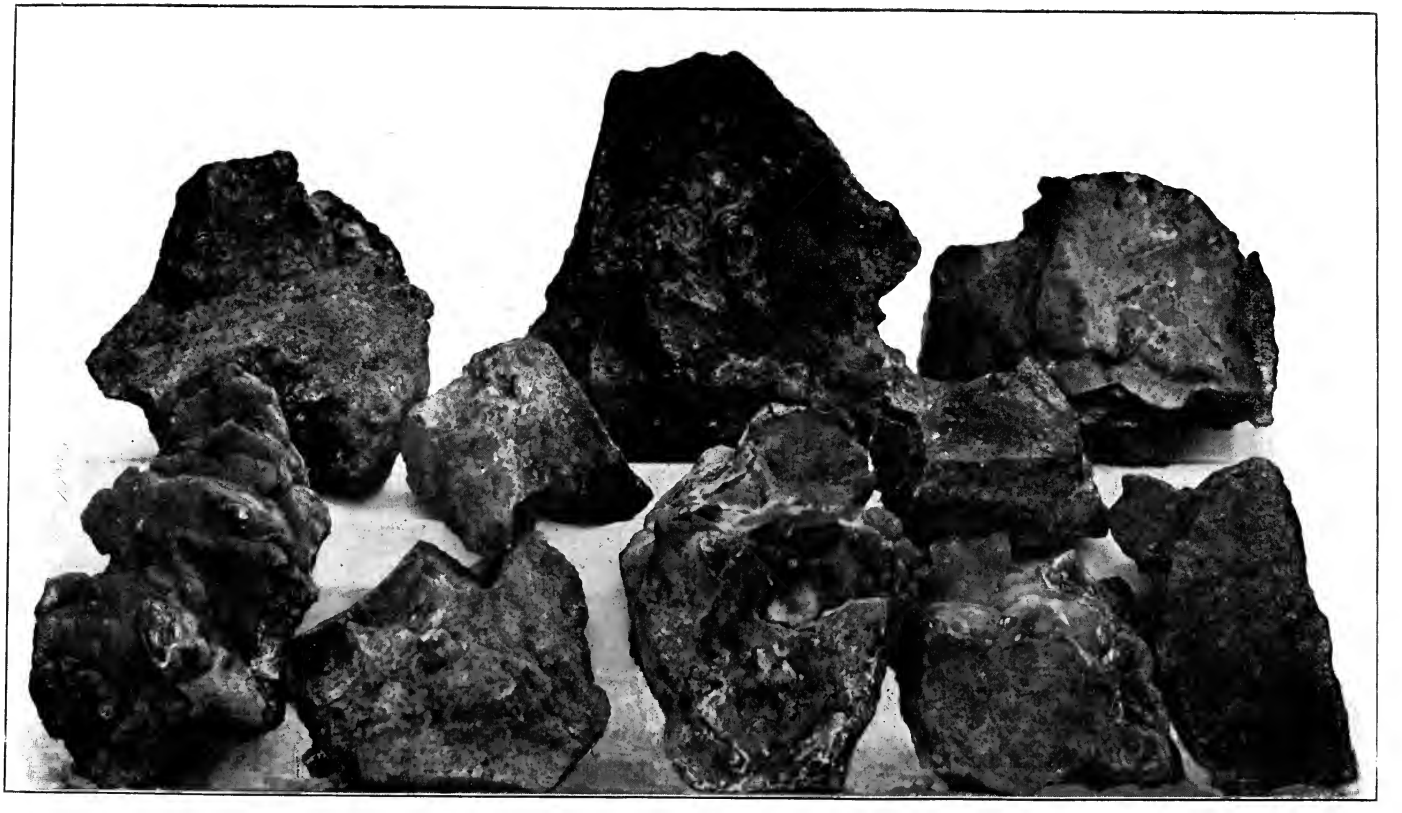

EXHIBIT No. 4. 43

SCALE BETWEEN TUBES OF BOILER; CAUSED A THIN TUBE TO COLLAPSE.

(C. S. Garrett & Son Co., Childs, Md.)

whereby its life is considerably reduced. It also endangers the safety of boilers."

Suspended matter, such as fine sand, and especially paper-pulp, settling on crown-sheets causes collapse.

In speaking of locomotive boilers, M. E. Wells (Pac. Ry. Club, 1903) says that by carefully cooling down and washing boilers he

(Parker Boiler Co.)

Exhibit No. 5.

found that the more carefully this was done the more white mud came down to be washed out, the percentage analysis of which was:

Sulphate of lime ($CaSO_4$)	4.90
Carbonate of lime ($CaCO_3$)	32.62
" " magnesia ($MgCO_3$)	30.62
Silica (SiO_2)	1.12
Water (H_2O)	31.90

It is largely made up of the carbonates of lime and magnesia.

After some months the scale from the properly cooled boilers became noticeably less, until the scale averaged the thickness of

an egg-shell, which would detach itself when it reached a certain thickness.

These shell-scales from boilers on divisions of the railroad 400 miles apart were analyzed as follows:

	No. 1.	No. 2.
Water (H_2O).....	11 24	22.78
Silica (SiO_2)	3.14	7.62
Al_2O_3 and Fe_2O_3.....	.....	3.10
Calcium (CaO).....	22.10	31.00
Magnesia (MgO).....	24.10	7.68
Sulphuric acid (SO_3).	35.29	21.91
Undetermined.....	4.13	6.61

(Fidelity & Casualty Co)

FIG. 6.—Accumulation of Scale in Flue Ends.

These analyses show principally lime and magnesium sulphates, which form the scale when the boilers are cooled down slowly.

G. M. Davidson,* chemist and engineer of tests, C. & N.W.

* Western Railway Club, Feb. 1903.

Ry. Co., states that the scale in locomotive boilers is due to one or more of the following causes:

1st. Deposition of lime and magnesia carbonates, due to the boiling off of the carbonic-acid gas from the water in which they were dissolved.

2d. Deposition of sulphate of lime, due to high temperature in the boiler.

3d. Deposition of magnesia compounds, due to their decomposition in the boiler.

4th. Deposition of sand, clay, and other matter that was suspended in the water.

5th. Deposition of alkali salts, due to concentration.

Analysis of Boiler-scale.—A boiler-scale containing some oil had this analysis:

SiO_2	7.36	per cent
$Al_2O_3+Fe_2O_3$	1.91	" "
$CaCO_3$	62.71	" "
$MgCO_3$	18.15	" "
$Mg(OH)_2$	4.21	" "
H_2O at 110° C.	2.51	" "
Oil (lubricating)	3.53	" "
Undetermined	0.62	" "

Some scales, notably oxides of calcium and magnesium, take up a large amount of water of hydration; one such example from Birmingham, Ala., after this water was driven off by heating to constant weight, gave these results:

Silica and clay	11.70	per cent
$Al_2O_3+Fe_2O_3$	2.81	" "
$CaSO_4$	1.69	" "
$CaCO_3$	5.45	" "
$MgCO_3$	7.36	" "
$Ca(OH)_2$	13.70	" "
$Mg(OH)_2$	56.37	" "
H_2O (moisture at 212° F.)	0.69	" "
Undetermined	0.21	" "
	99.97	per cent

A Corliss engine, using steam at 120 pounds pressure, was connected to a surface condenser. Ordinary filtration did not remove the oil in the condensed steam from the air-pump; a patent filter,

with a chemical arrangement for coagulating the oil with alum, was used with entire success, the purified water being as clear as spring-water.

The higher the temperature of the feed-water, the more impurities will be settled as scale or powder; in some cases water is taken from the boiler, and, as in one instance, passed through a Hyatt filter, circulation being induced by means of a Blessing trap.

In Sweet's rolling-mill, Syracuse, N. Y. (1892), the water was drawn from the blow-off cock of the boiler, and treated, filtered, and passed into a small boiler carrying a higher steam-pressure than the main battery, and from there back to the main boilers, thereby throwing down more impurities than in the main battery.

Mr. W. B. Cogswell says that at the Solvay Process Company's works at Syracuse, N. Y., they use (1902) a weak soda-liquor, containing about 12 to 15 grains Na_2CO_3 per liter. Say $1\frac{1}{2}$ to 2 cubic meters (397 to 530 gallons) of this liquor are run into the precipitating-tank. Hot water, about 60° C., is then turned in, and the reaction and precipitation go on while the tank is filling, which requires about 15 minutes. When the tank is full the water is filtered through the four Hyatt 5-ft.-diameter and the one Jewell 10-ft.-diameter filters in 30 minutes. Forty tanks are treated in 24 hours. Charge of water purified at once, 9275 gallons. Soda in purifying reagent, 15 kilograms Na_2CO_3. Soda used per 1000 gallons, 3.5 pounds.

Analysis of lake water, January 1, 1892:

Calcium sulphate	.261	grams	per	liter
Calcium chloride	.183	"	"	"
Calcium bicarbonate (as $CaCO_3$)	.091	"	"	"
Magnesium bicarbonate (as $MgCO_3$)	.015	"	"	"
" chloride	.087	"	"	"
Salt	.63	"	"	"

Analysis of mud from Hyatt filter:

Silica	15.17	grams	per	liter
Iron and aluminum oxide	3.75	"	"	"
Calcium sulphate	3.70	"	"	"
Magnesium carbonate	1.11	"	"	"
Calcium carbonate	63.37	"	"	"

Analysis of scale from boiler-tube, November 14, 1887:

Silica	2.29	grams per liter
Iron and aluminum oxide	1.10	" " "
Calcium carbonate	19.76	" " "
Magnesium carbonate	25.21	" " "
Calcium sulphate	51.24	" " "
NaCl	.14	" " "
	99.74	grams per liter

Analysis of scale found in pump, pumping from tanks through filters:

Silica	.8	grams per liter
Iron and aluminum oxide	1.2	" " "
Calcium carbonate	87.	" " "
" sulphate	10.9	" " "
	99.9	grams per liter

A sample is taken from each boiler every other day and tested for degrees Baumé soda and salt.

If the degree Baumé is more than 2, that boiler is blown to reduce it below 2° Bé.

Samples taken from twelve boilers on Feb. 10, 1889, when canal-water was used for steam, gave the following results on testing for degrees Baumé Na_2CO_3, Na_2SO_4, and NaCl:

Boiler.	Degree Baumé.	Na_2CO_3.	Na_2SO_4.	NaCl.
No. 1	1.	2.86	3.39	.94
" 2	1.8	5.14	6.51	1.31
" 3	.8	1.53	1.63	.585
" 4	1.6	4.24	5.51	1.52
" 5	2.4	6.62	8.97	2.34
" 6	1	2.49	2.92	.906
" 7	2	5.56	7.91	2.77
" 8	2.8	8.42	10.36	1.98
" 9	1.6	4.45	5.77	1.57
" 10	1.2	2.86	3.47	1.02
" 11	1.6	4.24	5.9	1.58
" 12	3.1	6.51	15.8	2.19

The analysis of the canal-water at this time was:

$CaSO_4$	.246	grams per liter
$CaHCO_3$ as $CaCO_3$	.031	" " "
NaCl	.043	" " "
$MgCl_2$	.038	" " "

It will be seen that at this time the carbonate of soda and sulphate of soda were present in greatest quantity, and the boilers had to be blown to keep these down in saturation.

This was not the case on January 1, 1892. The salt in the lake-water is now very high. More than twenty times the amount is now present in the lake-water, and hence the high degree Baumé is caused by the salt more than by the sulphate and carbonate of soda.

The following is test of degrees Baumé Na_2CO_3 and salt on January 1, 1892:

	Degree Baumé.	Grams per Liter.	
		NaCl.	Na_2CO_3.
No. 1	1.0	7.87	.848
" 2	.3	3.56	.318
" 3	2.7	17.30	2.96
" 4	1.9	10.99	1.84
" 5	2.6	16.66	.42
" 6	.5	4.09	2.96
" 7	2.8	17.30	3.71
" 8	3.4	20.00	4.1
" 9	3.4	21.52	3.18
" 10	3.0	18.72	3.00
" 11	2.7	16.66	3.18
" 12	2.5	15.08	3.00

It would then be much better to use in the boilers canal-water instead of lake-water, to avoid this large percentage of salt.

The analysis of the canal-water is:

CaSO	.223
CaCl	None
CaCO	.088
MgCO	.08
NaCl	.04

One man attends to the work during the day and one during the night.

PURIFICATION OF WATER AT LAKE PUMP.*

Amount purified per day (24 hours), 13,000 gallons.

Soda used, 40 pounds in 24 hours.

Soda per 1000 gallons, 3¼ pounds.

Fliter used, a Bunnell, 3 feet 6 inches in diameter, and 5 feet high. Washed twice in 24 hours.

The soda (about 20 pounds) is dissolved in 90 gallons of water, and this solution is mixed in the top of the filter with water from the hot-well and the circulating water from the boilers at 65° C., and is then filtered. Filter washed twice in 24 hours. There is no scale now in these boilers.

Rules for Preventing Scale.—J. C. Simpson,† of the Boiler Insurance and Steam-power Company, read a paper in 1894 at Hull, England, on Incrustation in Steam-boilers, and recommended these rules for lessening incrustation troubles:

1. The blow-off top should be opened the first thing in the morning, and again at starting after stoppage at each meal, and kept open for twenty seconds at a time.

2. A suitable fluid should be put in regularly with the feed-water.

3. When the time came round for boiler-cleaning, the water should be kept in after the steam is blown out, the dampers opened, and the brickwork allowed to cool for thirty-six hours, if practicable, after which the water should be run out, and the cleaners sent in as soon as possible.

Removal of Scale.—Aside from the results obtained when water has been chemically treated and leaves a soft, pliable, muddy deposit or sludge, which can be readily blown out, or taken from the boiler by hand, there is the hard scale, only to be removed by using edged tools, which method is not only hard work, often dangerous to the boiler itself, but it is also expensive.

There are many patented devices on the market for removing scale and cleaning boilers by machinery, many of which are very effective and good; but we will not describe them here.

Do not turn cold water into a steam-boiler which is already hot, and crack the scale and loosen it, so that it can be easily taken

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*Trans. A. S. M. E., Vol. 13. † Eng. Record, Vol. 29, p. 94.

out, for such a course is disastrous to the boiler, and the boiler-maker will be required to do much work before your boiler will be fit for service.

The *Engineering Record* well says: "A boiler-plant which is supplied with impure water should be in two parts, one a purifying apparatus, and the other the boiler proper; and these should be entirely distinct from each other."

The purifier removes the scale-making material and other impurities from the water, and deposits it where it can be readily removed and where it will do no harm. The boiler then has to perform simply the functions of generating steam, and with pure water the heating-surfaces can be arranged in the best manner to secure efficiency without regard to the deposit of scale.

Water is a poor conductor of heat; and since the heat imparted to boiler-waters is, in the case of the best-designed boilers, on the bottom of the shell or tubes, and the circulation is generally conceded to be in vertical lines or planes, the heated water passes upward and its place is taken by slightly cooler water in its turn; therefore, to secure the highest results in evaporative efficiency, the contact or medium of heat transmission between the furnace-fire and the water must be in the most perfect and clean condition possible, and maintained in that condition.

The steel shell is this medium, except in a very few cases where other metals are used, and is a good medium when clean. The instant that its outer or inner surface (we are dealing principally with the inner) becomes coated or insulated in any way, there is an immediate reduction in the evaporative efficiency of the boiler, which depends upon the amount, solidity, and the general character of the coating or scale; a very thin scale frequently produces easily detected loss of efficiency.

Conduction of Heat.—Conduction is the movement of heat through substances, or from one substance to another in contact with it. The table herewith contains the relative internal conducting power of metals and earths, according to M. Despretz. Bodies which are finely fibrous, as cotton, wool, eider-down, wadding, and finely divided charcoal, are the worst conductors of heat. Liquids and gases are bad conductors, but if suitable provision be made for the free circulation of fluids they may abstract heat very quickly by contact with heated surfaces, acting by convection. Con-

vection, or carried heat, is that which is transferred from one place to another by a current of liquid or gas; for example, by the products of combustion in a furnace towards the heating-surface in the flues of a boiler.

Substance.	Relative Conducting Power.	Substance.	Relative Conducting Power
Gold	1000	Zinc	363
Platinum	981	Tin	304
Silver	973	Lead	180
Copper	892	Marble	24
Brass	749	Porcelain	12
Cast iron	562	Terra-cotta	11
Wrought iron	374		

D. K. Clark, Manual of Rules, Tables, Data, etc., p. 331.

Transmission of Heat.—Experiments of the transmission of heat; that is, units of heat a plate $\frac{1}{8}$ inch thick will transmit per square foot per hour if supplied with an unlimited amount of water on one side and steam on the other:

Cast iron	265 units
Wrought iron	252 "
Steel	246 "
White metal	207 "
Brass plates	175 "
Gun-metal	168 "
Phosphor-bronze	162 "
Copper	155 "
Tin-plate	142 "
Glass-plate	259 "
Tiles	246 "

W. S. Hutton, 1887.

Tiles and glass are very much superior to copper and tin for the transmission of heat, but have less conductivity.

The effect of scale in a boiler is shown by this extract from report of tests made in a boiler in the Conservatory, France:

	Water Vaporized per Hour.	Coal Burned per Hour.	Steam per Kilo of Coal per Hour.
Boiler, clean	200 liters	25.5 kilos	8.50
" scaled	136 "	34.7 "	3.87

Tower, p. 87.

After a long period of use we thus have the evaporative capacity compared to what it was when the boiler was clean.

An experiment * on the effect of scale on transmission of heat showed that a calcium-sulphate scale 0.11 inch thick caused a loss in evaporative efficiency of over 7 per cent.

In a set of experiments, J. Hirsch,† 1890, used a small kettle about 10 inches diameter with an iron bottom $\frac{3}{8}$ inch thick.

When this plate had been covered with scale $\frac{1}{5}$ inch thick the temperature of the fire side of the plate had to be increased an additional 460° when evaporating 55 pounds of water per hour.

Thus scale as in above tests offers five times the resistance to transmission of heat that iron does. Other experiments show ten times as the ratio of plaster of Paris to iron. Hirsch also proves the injurious results from allowing grease to settle on heating-surfaces.

Ten specimens of scale, three of lubricants, two of tar, and one of anti-scale substance were measured at about 30° C. (86° F.) by Christiansen's comparison method by W. R. Ernst,‡ in order to test whether scale-forming and other materials settling on boiler-surfaces are really conducive to boiler explosions and burnt plates.

The conductivity of the scale varied between 0.00313 and 0.00768 (that is, 3 to 7.4 times that of water) and that of other substances between 0.000253 and 0.000324. Calculations are made by means of these numbers of the temperatures of scale-covered surfaces under certain ordinary conditions of steam pressure and generation, and their results thoroughly justify the usual notions on the subject.

The conductivity of one of the specimens of scale diminished by 15 per cent when its temperature was raised to 110° C. (230° F.).

The transmission of heat through plates from hot gases on the one side to water on the other, from tests conducted by Blechynden, resulted in the conclusion that

$$Q=\frac{(T-t)^2}{A}.$$

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* J. A. Carney, Proc. A. Inst. Mining Engineers, 1897.

† Stromeyer, Marine-boiler Management, p. 95.

‡ Akad. Wiss. Wien, Sitz. Ber. 111, 2*a*, July 1902.

Q = B.T.U. transmitted per square foot per hour;
T = temperature of furnace at plate;
t = steam temperature or water temperature at steam side of plate;
A = a constant, which in the tests varied from 38.6 to 71.9.
200 to 400 is a value more likely to be obtained in steam-boiler tests, and, in fact, Schwackhofer (p. 33) gives, as the value of H, 560 to 700.

Blechynden also found that the slightest traces of grease caused a marked fall in the rate of transmission. Smoothness of surfaces had a marked influence on the rate of heat transmission also.

A. D. Risteen * outlines a method for calculation of the effect of scale on the transmission of heat by taking the temperature degrees F., or t measured just within the material of the plate where it is considerable less than in the fire itself just away from the plate, and t' the degrees F. just within the scale, using the formula

$$Q=\frac{t-t'}{rp}=\text{T.U. transmitted per square foot per hour.}$$

p = thickness of plate in inches;
r = a constant = specific internal thermal resistance of the plate material, which equals about 0.0043.

If there are two thicknesses or layers of different composition, let

s = thickness of layer of scale in inches.

The formula then becomes

$$Q=\frac{t-t'}{rp+Rs},$$

where R = specific internal resistance of the scale (Rankine gives $R=0.0716$ for calcium carbonate or marble);
T = temperature of furnace gases near plate;
t'' = temperature of water in boiler.

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* Amer. Man'f'r, Sept. 1904.

If T is made use of, being measured beyond the chilled film on the surface of the metal, we will need another formula in which so-called " surface " or skin resistance is represented by k, or

$$Q=\frac{T-t''}{k+rp+Rs}.$$

Rankine gives the value of k for boiler-plate as $=\frac{180}{T-t''}$, which substituted in the above gives

$$Q=\frac{(T-t'')^2}{180+(T-t'')(rp+Rs)}.$$

By using this formula for Q in the case of a clean boiler we have

$Q=6068$;

$t=359.8$, or less than 10° hotter than the water in the boiler.

Now considering a scale $\frac{1}{8}$ inch thick, everything else the same as before, we get

$Q=5770$;

$t=410.9$, or 60°.9 hotter than the water in the boiler.

The heat-absorbing power of the boiler has also been decreased about 5 per cent. " The efficiency of the boiler as a whole would not be reduced by as much as the 5 per cent here indicated, because the furnace-gases would enter the tubes at a higher temperature than they would have had if the boilers were free from scale, and hence the heat absorption in the tubes would be greater than before "; the heat absorption in the furnace likewise being less.

A partial compensation would then result, and the efficiency would not actually fall off the 5 per cent as calculated for plate and scale.

Conductivity of Scale. — Tests made by members of the N. A. S. E., No. 31, Brooklyn, N. Y., and reported in *Power*, 1896, showed the relative conductivity of different substances as used in boilers to be:

Brass	4
Plaster of Paris	26
Portland cement	71

A vessel coated $\frac{3}{32}$ of an inch with plaster of Paris steamed just as quickly as a clean one.

A sample of scale was tested which had the same conductivity as the plaster of Paris.

THERMAL CONDUCTIVITY OF SOLIDS.*

Observer.	Materials.	G. C. S. Scale.	English Scales.	
			Thermal Units.	Evaporative Units.
1	Iron at 32° F.	.207 to .154	603 to 449	.621 to .462
1	" " 212° F.	.157 to .129	456 to 375	.472 to .387
1	" " 527° F.	.124 to .112	361 to 297	.372 to .306
2	"	.164	477	.492
3	"	.199 (1 − .0029t° C.)	610 (1 − .0015t° F.)	.6 (1 − .0015t° F.)
3	Copper.....	1.027 (1 − .0021t° C.)	8140 (1 − .00115t° F.)	3.08 (1 − .0021t° F.)
2	"	1.108	3220	3.024
2	Brass.....	.302	878	.906
2	Zinc.....	.307	892	.921
2	German silver.....	.109	317	.327
2	Slate, along cleavage	.0055 to .0065	160 to 190	.0165 to .0195
2	" across "	.00315 to .0036	92 to 105	.0095 to .0108
1	"	.0081	23.5	.0243
2	Clay, sun dried.....	.00223	6.6	.00669
2	Chalk.....	.0020 to .0033	5.8 to 9.6	.006 to .010
2	Fire-brick.....	.00174	51	.00522
2	Plaster of Paris, wet.	.00164	48	.00492
2	Coal.....	.00057 to .00113	1.65 to 3.3	.0017 to .0034
2	Pumice-stone.....	.00055	1.60	.00165
4	Various woods.....	.00026 to .00359	.76 to 1.71	.00078 to .00177
4	Caoutchouc.....	.00041	1.19	.00123
1	" vulcanized	.000089	.258	.000267
4	Gutta-percha.....	.00048	1.40	.00144
4	Powdered charcoal..	.00022	.64	.00066
4	" coke.....	.00044	1.28	.00132
4	Charred wood.....	.000122	.35	.000366
4	Gray paper.....	.000094	.273	.000282
1	Pasteboard.....	.000453	1.33	.00136
1	Paraffin.....	.00014	.41	.00042
1	Flannel.....	.0000335	.097	.0001
5	Water.....	.00136	4.00	.004

Observers.—1. Forbes; 2. Neumann; 3. Angstrom; 4. Peclet; 5. Weber

* Stromeyer, Marine-boiler Management.

In this table thermal units are the units of heat which 1 square foot of heating-surface 1 inch thick will transmit per hour, with a difference of temperature on the two surfaces of the plate of 1° F.

Evaporative units are thermal units divided by 966, the T.U. required to evaporate one pound of water from and at 212° F.

Evaporative units can also be obtained by multiplying the figures in G.C.S. column by 3.

These experiments were made on rods or rings and do not give precisely the same results as plates do.

Mr. J. E. Bell,* in a paper before the Ohio Soc. of Mech., Elec., and Steam Engineers (1904) on the effect of boiler conditions on efficiency, referred to a boiler having a slight coating of scale and all the dust it could hold on every portion of tubes, etc., which gave an equivalent evaporation of 8.04 pounds per pound of dry buckwheat coal when boiler was in above condition and 10.3 pounds after boiler had been cleaned.

Another case concerning thickness of fires is also noted: A pumping-plant operated under identical conditions gave a duty of 93,000,000 foot-pounds when the fire was 8 to 9 inches thick and 143,000,000 foot-pounds when the fire was 14 to 15 inches thick. A high-grade semi-bituminous coal was used.

Transmission of Heat through Scale-covered Boiler-tubes.—A series of experiments were conducted by F. L. McCune in 1901, at the University of Illinois, to determine the relative conductivities for heat of clean and scaled locomotive-boiler tubes.

Tubes were furnished by different railroads, and were tested in a special apparatus in which hot gases passed through the tubes and water around them received the heat.

The tests are very fully described in the *Railroad Gazette*, June 14, 1901, p. 408, in which paper is also a drawing of the apparatus used.

TUBES TESTED.

Tube No.	Railroad.	Time in Service, Months.	Diameter of Tube.		Average Thickness of Scale, Inch.
			Inside.	Outside.	
2	P. & E.	13½	1.75	2.00	0.04
3	"	5½	1.75	2.00	0.02
5	C., M. & St. P.	....	1.75	2.00	0.13
6	I. C. R.R.	5½	1.75	2.00	0.07
7	P. & E.	37½	1.75	2.00	0.04
9	C., B. & Q.	....	1.75	2.00	0.07
11	I. C. R.R.	21	1.75	2.00	0.09
14	P. & E.	....	1.75	2.00	0.00

* *Eng. Rec.*, Vol. 51, p. 53.

The character of the scale for the various tubes was as follows:

Tube No. 2, soft, porous, mud-colored, off in places;
" " 3, even, hard, dense, white;
" " 5, even, hard, dense, mud-colored;
" " 6, mileage during service, 19,690;
" " 7, hard, dense and rough, one end; soft and porous at the other;
" " 9, hard, porous, gray; mileage, 50,889;
" " 11, soft, porous;
" " 14, clean tube.

TRANSMISSION OF HEAT THROUGH TUBES.

Tube No.	Averages for the Various Tests of Each Tube.			
	Range of Temp. between Water and Gases	B.T.U Transmitted through the Tube During the Tests.	B.T.U. which would have been Transmitted had the Range of Temp. been the Same as for Tube 14.	Decrease of Conductivity Due to the Scale, $\frac{29854 - \text{Col. D}}{29854} \times 100$.
A	B	C	D	E
2.....	859.4	27370	27816	6.82
3.....	877.3	27258	27137	9.10
5.....	855.9	27270	27828	6.75
6.....	899.3	30675	29792	0.21
7.....	886.5	29370	28936	3.07
9.....	820.8	23362	24859	16.73
11.....	882.2	26937	26680	10.63
14.....	873.4	29854	29854	Clean tube

The above illustrates how great may be the losses from scale on tubes, also how variable a quantity the loss is with various kinds of scale and from water of different localities.

Effect of Scale on Evaporative Power of a Locomotive Boiler.—The mechanical engineering department of the University of Illinois in 1898 conducted a series of tests on a locomotive to determine its evaporative efficiency, with clean or scaled water-surfaces.

The locomotive tested was a Mogul, No. 420, on the Illinois Central R. R., built by the Rogers L. & M. Works of Paterson, N. J., and had been in use twenty-one months.

The tests were made in the round-house and by the " standard " method.

The following are the locomotive's principal dimensions and proportions:

Cylinders, 19 inches diameter.
Stroke, 26 inches.
Diameter of drivers, 56½ inches.
Total weight of engine, 126,000 pounds.
Diameter of boiler, 62 inches.
Tubes, 236; 2 inches diameter, 11 feet $\frac{15}{16}$ inch long.
Fire-box, 114⅛ inches long by 33⅜ inches wide.
" depth, front end, 67⅞ inches.
" " back " 59⅞ "
Length of grate, 114⅛ inches.
Width " " 33⅜ "
Diameter of steam-dome, 29⅛ inches.
Lagging of boiler, magnesia sectional.
Grate-area, 26.45 square feet.
Total heating-surface, 1531.65 square feet.
Area of draught through tubes, 573.48 square inches.
Ratio, grate- to heating-surface, 1 to 57.91.
Fuel, ordinary mine-run.
Lumps, 75 per cent; small coal, 20 per cent; slack, 5 per cent.
B.T.U. per pound of dry coal by calorimeter, 12,240.

The results of these tests are given in the tables on page 60, and a condensed table of results is given here:

	Scale in Boiler.		Clean Boiler.	
Date of trial, 1898	May 2	May 3	May 31	June 1
Duration of test, hours	8.33	8.17	8.03	8.16
Steam pressure, by gauge	143.	140.	116.4	114.
Vacuum in smoke-box, inches water	2.0	2.0	2.9	2.8
Temperature of feed-water, deg. F.	57	54	58.5	59.4
" " escaping gases, deg. F	623	670	621	687
Moisture in coal	4.	4.	4.	4.
Per cent ash (from ash-pan)	15.6	15.6	16.6	18.7
" " moisture in steam	2.25	2.25	2.85	2.85

The loss due to scale in the boiler was 9.55 per cent. Average thickness of scale on principal heating-surface $\frac{3}{64}$ inch. 360 pounds were removed from the tubes and 125 pounds were removed from the shell and fire-box sheets, a total of 485 pounds.

Tests of Locomotive Boiler, Illinois Central Eng. No. 420, after 21 Months' Service.*

Scale 1/32 to 1/16 inch thick, and after cleaning and new tubes put in. Loss due to scale, 9.55 per cent.

	First Series. Scale in Boilers.			Second Series. Clean Boilers.		
Date of trial	5-2-'98	5-3-'98	Mean	5-31-'98	6-1-'98	Mean
Water actually evaporated per pound of dry coal, lbs.	5.21	5.27	5.24	5.81	5.85	5.83
Equivalent water from and at 212° F. per pound dry coal, lbs.	6.29	6.39	6.34	6.99	7.04	7.01
" " " " " " " " " combustible, lbs	6.17	6.25	6.21	6.95	7.16	7.05
Water actually evaporated from and at 212° F., per pound comb., lbs.	7.46	7.59	7.53	8.35	8.61	8.48
Dry coal burned per hour: Per sq. ft. of grate-surface, lbs.	57.45	58.51	57.95	59.8	60.0	59.9
" " " " " tube-opening, lbs.	394.8	402.1	398.4	411.0	412.8	411.9
" " " " " water-heating surface, lbs.	0.93	0.95	0.94	0.97	0.98	0.97
Water evaporated per hour from and at 212° F.: Per sq. ft. of grate-surface, lbs.	361.8	374.4	368.1	418.0	416.0	417.0
" " " " " tube-opening lbs.	2486.	2573.	2529.	2874.	2857.	2865.
" " " " " water-heating surface, lbs.	5.89	6.09	5.99	6.81	6.76	6.785

RESULTS OF BOILER-SCALE ANALYSIS.

Scale from Point No.	1	2	3	4	5	6	7	8	9
Analysis of Scale.	Composition in								
Silica	7.70	25.20	8.00	7.84	15.89	11.25	18.25	13.05	22.70
Iron and aluminum oxide	3.20	7.10	4.99	3.27	4.30	7.70	6.90	7.85	12.75
Calcium carbonate	65.81	20.92	48 90	61.17	30.36	67.08	45.51	24.33	28.32
Magnesium carbonate	.....	3.05	.....	8.14	8.71	.....	.....	.....	5.86
Calcium sulphate	10.86	16.45	21.22	4.38	21.38	1.97	1.95	40.03	11.73
Magnesium sulphate	.....	.....	.....	.....	.....	.....	.....	.....	.....
Calcium oxide	.....	.....	1.90	.....	.....	.....	5.09	1.14	
Magnesium oxide	9.55	19.52	4.48	5.47	7.66	9.29	16.77	9.12	18.45
Loss on ignition, and undetermined	2.78	7.76	10.51	9.73	11.70	2.71	4.93	4.48	0.11

* R.R. Gaz., Vol. 31, p. 60. L. P. Breckenridge.

The quality of scale from various parts is noted below; the reference numbers refer also to table of analysis.

Point No. 1. Near injector-discharge, hard and soft scale $\frac{1}{8}$ inch thick;
" " 2. On upper tubes, hard smooth scale, uniform thickness of $\frac{1}{32}$ inch;
" " 3. On lower tubes, hard scale near middle, $\frac{1}{16}$ inch thick;
" " 4. Mud covering hard scale at No. 3, $\frac{3}{32}$ inch thick;
" " 5. Scale from side sheet, flue-sheet and tubes, rough and scaly;
" " 6. From bottom of barrel, 4 feet from flue-sheet;
" " 7. On crown-stays, 3 to 6 inches from crown-sheet;
" " 8. On crown-sheet, rivet-heads and base of stays;
" " 9. From the water-line on vertical stay-bolts.

Note that the calcium carbonates deposit easily without high heat, that is, near the injector-discharge (Point No. 1) and in bottom of the boiler (Point No. 6), while on the crown-sheet (Point No. 8) the scale carries the largest percentage of calcium sulphate.

The boilers were supplied with good feed-water, as is evidenced by the comparatively small amount of scale accumulating in the lengthy period of twenty-one months.

More complete details and two cost diagrams may be found in the *Railroad Gazette* of Jan. 27, 1899.

Thermal Conductivity.—The relation between thermal and electrical conductivity is given by H. F. Weber, 1880, as

$$\frac{T}{E}=(0.0877+0.136\sigma)10^4;$$

where T = thermal conductivity;
E = electrical conductivity;
σ = specific heat of the substance.

Scale-forming Solids.—C. L. Kennicott, in Proc. Western Ry. Club, 1903, gives this rule for finding the weight of scale-forming solids entering a boiler: Take any analysis, divide the number of grains (per American gallon) of incrusting solids by 7, and you have the pounds per 1000 gallons; multiply this result by the number of " 1000 gallons " used in a given time and you have the weight of incrusting solids entering the boilers.

AMOUNT OF SEDIMENT COLLECTED IN A STEAM-BOILER WHEN EVAPORATING 1000 GALLONS OF WATER PER DAY, 6000 GALLONS PER WEEK, GALLONS OF 58,318 GRAINS EACH.

When a Gallon of Feed-water Evaporated to Dryness at 212° Fahrenheit Leaves of Solid Matter in Grains.	The Amount of Solid Matter Collecting in Boiler per Day will be		The Amount of Solid Matter Collecting in Boiler per Week will be	
Grains.	Pounds.	Ounces.	Pounds.	Ounces.
1	...	2.286	...	13.714
2	...	4.571	1	11.428
3	...	6.857	2	9.143
4	...	9.143	3	6.857
5	...	11.428	4	4.571
6	...	13.714	5	2.285
7	1	.....	6	.....
8	1	2.286	6	13.714
9	1	4.571	7	11.428
10	1	6.857	8	9.142
15	2	2.285	12	13.713
20	2	13.714	17	2.284
25	3	9.142	21	6.855
30	4	4.571	25	11.426
35	5	.....	30	.....
40	5	11.428	34	4.571
45	6	6.856	38	9.143
50	7	2.285	42	13.714
55	7	13.713	47	2.285
60	8	9.142	51	6.857
65	9	4.571	55	11.428
70	10	.....	60	.....
75	10	11.428	64	4.571
80	11	6.857	68	9.143
85	12	2.286	72	13.714
90	12	13.714	77	2.285
95	13	9.143	81	6.857
100	14	4.571	85	11.428
110	15	11.428	94	4.571
120	17	2.286	102	13.714
130	18	9.143	111	6.857
140	20	.....	120	.....
150	21	6.857	128	9.142
160	22	13.714	137	2.285
170	24	4.571	145	11.428
180	25	11.428	154	4.571
190	27	2.286	162	13.714
200	28	9.143	171	6.857
210	30	.....	180	.....

Locomotive, 1884.

The above table was prepared by F E Engelhardt, Ph.D., of the American Dairy Salt Company, Syracuse, New York. It represents the total amount of solid matter, or sediment, deposited under the conditions of the boiler making steam without any water being drawn or blown off, or any cleaning whatever, and shows the necessity for such cleaning even in the case of a good feed-water

Composition of Boiler Incrustations from Different Waters.

Number.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Source.	Sea-water.				Brackish Water.	River-water.				Wells.		Town Supply—Edinburgh.	Spring—Slough.	Pits & Surface—Prestonpans.	Quarry—Granton	An Acid Water
							Carlisle.		Thames.	Dunbar.	Slough.					
Pressure in pounds per square inch.	5	10	20	25(?)	.....	.....	.....	60	80							
$CaCO_3$	2.00	3.44	0.34	0.97	43.65	75.85	75.92	8.20	81.45	32.16	25.62	62.95	50.04	1.22	17.31	2.20
$CaSO_4$	34.00	69.77	72.85	85.53	34.78	3.68	3.16	85.01	1.63	5.64	55.92	20.80	29.76	78.32	53.76	
$Mg(OH)_2$	58.00	22.50	18.83	3.39	4.34	2.56	.....	4.36	8.10							
$MgCO_3$	.....	.....	.....	.....	.....	.....	10.16	.....	.....	20.04	5.56	7.24	10.84	10.36	18.04	None
Na salts	.....	.....	.....	.....	.....	.....	0.84	.....	.....	3.31	.....	0.86	0.86	0.64	0.54	
NaCl	Trace	0.99	2.16	2.79	0.56	0.45	.....	Trace	Trace	.....	0.22					
Fe_2O_3, Al_2O_3, and $Ca_3(PO_4)_2$	1.33	1.36	2.40	0.32	3.44	2.96	2.96	0.52	2.44	7.46	5.04	2.48	2.36	4.64	2.88	83.80
SiO_2	Trace	0.16	0.80	1.10	7.52	7.66	4.94	1.91	0.87	16.94	5.26	3.76	4.28	3.22	4.36	5.28
Organic matter	4.67	1.78	2.62	Trace	1.55	3.64	0.49	Trace	4.65	7.67	1.04	0.69	0.64	0.88	2.33	8.72
Moisture				5.90	4.16	3.20	1.53		0.86	6.78	1.34	1.22	1.22	0.72	0.78	

Notes —These analyses are only comparative in a general sense, as they were done under different circumstances. They, however, furnish good examples of the effects of varying conditions.

Nos. 1, 2, 3, 4 show the increasing proportion of calcium sulphate precipitated with an increasing pressure, and therefore temperature.

In Nos. 6, 7, 9, 10, 12, the waters were of the carbonate of lime class, in which the temporary hardness is predominant.

In Nos. 8, 14, 15, the waters had a high permanent hardness, due to sulphate of lime.

No. 10 is a magnesian water. The high amount of silica is remarkable, also the action on iron.

No. 16 shows the action of a soft and acid water on iron. The small quantity of carbonate of lime has probably been protected by the iron scale.

The proportion of organic matter is seen to vary greatly.

As boiler-crusts usually contain magnesium hydrate only, the magnesium carbonate found in some of the above analyses must be due to the absorption of carbonic acid from the air by the crust after removal.

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Scale.—Prof. V. B. Lewes, Inst. Nav. Archts., vol. 30, 332, gives these analyses of incrustations formed in the boilers of steamers using fresh river-water, brackish water at the mouth of the river, and sea-water respectively:

	River.	Brackish.	Sea.
Calcium carbonate	75.85	43.65	0.97
" sulphate	3.68	34.78	85.53
Magnesium hydrate	2.56	4.34	3.39
Sodium chloride	0.45	0.56	2.79
Silica	7.66	7.52	1.10
Oxides of iron and alumina	2.96	3.44	0.32
Organic matter	3.64	1.55	Trace
Moisture	3.20	4.16	5.90
Total	100.00	100.00	100.00

ANALYSES OF SIX SPECIMENS OF SCALE. (PROF. CHANDLER.*)

	Averages.
Sulphate of lime	56.49
Carbonate of lime	18 11
Basic carbonate of magnesia	19.77
Oxide of iron and alumina	0.69
Silica	3.81
Organic matter	
Water	1.62
	100.00

W. E. Ridenour † classifies boiler-scales in this way:

A. The calcium-sulphate scales;
B. The calcium-carbonate scales;
C. The silica scales;
D. The magnesia scales.

The class B scales are moderately soft. The class A scales are, as a rule, very hard and porcelain-like, and can be told with the aid of a magnifying-glass by their glassy or vitreous appearance.

Class C scales are strange and interesting and most common in the Southern States, though occurring in other quarters.

The silica scales have no characteristic physical properties.

* Tower, p. 81. † Jour Frank. Inst., Vol. 152, p. 113.

SILICATE SCALE ANALYSES.

	1.	2.	3.	4.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Calcium carbonate	36.40	7.47		
" oxide	7.32	21.94	36.42	5.42
" sulphate	.....	.....	.....	3.95
Silica.	41.00	51.07	40.51	48.02
Magnesium hydrate	.50	2.74	3.04	3.58

1 Louisiana; 2. New Jersey; 3. Olympia, Wash.; 4. Pennsylvania.

Class D, or magnesium scales, has been the subject of differences between chemists, but the hydrate is the generally accepted combination.

A Texas scale contained 82.95 per cent of magnesium hydrate, 7.50 per cent of calcium sulphate, and 3.10 per cent of silica.

Mr. Ridenour refers to a scale 96 per cent calcium carbonate which came from near the feed-pipe where the water receives its first high heat; driving off carbonic acid and precipitating the carbonate, the calcium sulphate passes on in the boiler and is found in another scale 76 per cent calcium sulphate.

V. B. Lewes mentions the variety in chemical composition of scales taken from different parts of the same boiler.

From analyses, Didos, in reviewing European practice, says more than 75 per cent of scale deposited from river-water is carbonate of lime and only 3 per cent sulphate of lime, while for brackish water the proportions are nearly equal, 40 per cent each.

For sea-water the other extreme is reached, for we find 85 per cent of sulphate and less than 1 per cent of carbonate.

Hydrate of magnesia is not over 4 per cent in any of these cases; its presence, however, causes harder scale than otherwise would be the case.

PITTSBURGH, PA., EXPERIMENTS.

In order to find out the effect of using filtered water in the boilers at the Brilliant Pumping Station,* a series of tests were made, using a locomotive-type boiler and water as follows:

No. 1. Effluent from the sand-filters;

No. 2. Effluent from the mechanical filters;

No. 3. Unfiltered water.

* Report of Pittsburgh Filtration Com., 1899, p. 216.

The general dimensions of the locomotive-type boiler were:

Horse-power, at 12 sq. ft. of heating-surface per H.P	30
Diameter of shell	40 inches
Length	14 feet
Height	8 "
Tubes, diameter	48 " 3 ins.
Tubes, length	93 inches
Heating-surface	369 square feet
Length of furnace	50 inches
Width " "	40 "

Gas was used for fuel from an 8-inch diameter main in which a pressure of about " 8 inches of water " was maintained. The details of the burners do not especially interest us here; the gas burned had its flow maintained at about 20 cubic feet per minute. Boilers No. 1 and No. 2 were fed with water by injectors; No. 3 was fed directly from the city main, under 140 pounds pressure.

After operating the boilers about two months, samples of the scale and sediment were collected and analyzed as follows:

	Parts by Weight.					
Number of sample	1	2	3	4	5	6
Weight in grams	19.88	40.02	29.91			
Calcium carbonate	33.11	17.78	32.11	3.79	7.36	1.82
" sulphate	52.03	56.98	47.46	3.77	30.23	2.38
Magnesium carbonate	1.99	3.21	1.96	0.00	1.54	0.70
Sodium chloride	0.00	0.00	0.78	88.32	53.82	0.00
Iron and aluminum oxide	2.76	5.20	1.64	0.40	2.20	85.86
Insoluble matter	10.11	16.83	16.05	3.72	4.85	9.24
Total	100.00	100.00	100.00	100.00	100.00	100.00
Scale $\frac{1}{32}$ inch thick in each. No. 1. Hand, tenacious. " 2. " brittle, cracks off easily. No. 3. Soft and powdery.	From crown-sheet of No. 1.	From crown-sheet of No. 2.	From crown-sheet of No. 3.	From hand-holes.	From hand-holes.	From side of fire-box of No. 3.

After the boilers were finally blown out they were returned to their makers, who cleaned them, and had the scale again analyzed,

but as the samples analyzed are not from the same place in each, comparisons cannot be made, so the results are not given here.

After a thorough examination by a boiler expert, these three boilers, which were new when tests were begun, were judged by him as follows: "In our opinion boiler No. 3 is in the best condition, for while there is considerable scale and sediment, it is soft, adheres loosely, and can easily be washed off and removed.

"The other boilers we would consider on a par, the only difference being that the rivets in No. 2 are badly corroded, and the tubes have a thicker coating than either of the others. Considering all things, we believe the boiler to be in the worst condition of the three."

This boiler, No. 2, used water from the mechanical filters, and the scale from this filtered water was very hard and porcelain-like.

The water supplied to No. 3 boiler and filtered for the other two boilers was of a

	June	July	August	
Total hardness.	3.51	4.53	3.99	parts per 100,000
Alkalinity.	3.10	3.41	3.15	
Sulphuric acid. .	1.04	1.55	0.93	
Chlorine.	2.42	2.47	2.42	

1898

An analysis of sample of raw water taken September 19, 1898, gave, in parts per 100,000:

Total solids.	12.70
Loss on ignition.	4.30
Calcium oxide, CaO.	2.04
Magnesium oxide, MgO.	0.49
Sulphuric acid, SO_3.	1.61
Chlorine, Cl.	2.20
Silica, SiO_2.	0.10
Iron oxide, Fe_2O_3.	0.01

CHAPTER III.

CORROSION.

CORROSION is the strongest destructive force acting against the life of a boiler.

All natural waters are more or less corrosive, for they all carry carbonic-acid gas and free oxygen, which are each capable of corrosive action; if the water also has salts in solution, they render it more corrosive.

In a general way iron is more capable of resisting corrosion than steel, though English mild steel is more liable to corrosion than iron.

In steam-boiler practice corrosion exists in two forms:

1. Externally;

2. Internally; as, uniform corrosion, wasting, pitting or honeycombing, and grooving.

The first, external, is due to the atmosphere or setting, and ashes under boilers. The second, internal, is due to the corrosive properties of the feed-water, and quality of material composing the boiler-shells, and is met by special treatment of the water, and in some cases by hanging plates of zinc in the water-space, of which we shall speak later.

When the space between the grate-bars and shell of the boiler becomes filled with ashes, they usually get wet and a major part stick to the shell; especially is this likely to happen in internally fired boilers, where the ashes attach themselves to the shell, and, as they absorb moisture, corrosion is soon a result.

The piece represented by Fig. 7 was taken from a furnace two years old, and was originally a full quarter of an inch thick; it was taken out just above the grate-bars, and, in some places was $\frac{1}{32}$ to

$\frac{1}{16}$ of an inch thick. The same condition was noticeable about the entire boundary of the fire-box. As a cautionary measure, never cool any ashes with water while they are under the boiler-grates.

(From "The Locomotive," Hartford S. B. I. & I Co.)

FIG. 7.—Effect of Corrosion, Result of Accumulated Ashes.

W. F. Worthington says that cold sea-water corrodes iron and steel equally, but that steel suffers much more than iron in hot sea-water.

Some writers assert that carbonic acid is necessary in waters that they may corrode the metal; others have proved that it is

not so. The amount of carbonic acid is small in sea-water, but is greater and more variable in river-waters.

Land-water may be easily tested for organic matter by adding a little sulphuric acid, H_2SO_4, when, if organic matter is present, the water will turn dark.

All corrosion in steam-boilers may be called oxidation, which in the case of iron, Fe, occurs in these common forms:

1. $Fe_2O_3+H_2O$, or ordinary yellow iron-rust, which is found on the outside of boilers.

2. Fe_2O_3, or red oxide of iron, which is found on the fire-box sheets and flues as pustules or pitting.

3. Fe_3O_4, or black or magnetic oxide of iron, which occurs from overheating, resulting from excessive scale or mud, or from electrolytic action.

Corrosion is frequently caused by copper ferrules being used on ends of boiler-tubes when expanding them in the flue-sheet; on this account soft-iron ferrules are to be preferred.

Howe's experiments have shown that when steel plates with mill-scale and plates free from mill-scale are connected galvanically, electric currents capable of measurement are set up, in which case the mill-scale is as active as the copper.

Tubes pickled in acid to remove scale should be washed in lime-water and then be baked for several hours at a temperature of 400° to 450° F.

Mill-scale may be removed from the outside of tubes with a sand-blast, and inside by using a bundle of rods and sand, and revolving the entire mass, holding the tube itself rigid.

Rear-Admiral C. M. Aynsley, C.B.,* gives, as the results of investigations by the Admiralty Boiler Committee, these causes of corrosion:

1. Water too pure for constant condensation;
2. Fatty acids from oils used for internal lubrication;
3. Quantity of iron used;
4. Particles of copper carried in by the feed;
5. Galvanic action;
6. The use of copper feed-pipe;
7. Bad management of boilers;

---

* Van Nostrand's Eng. Mag., Nov. 1880.

8. Copper in solution;
9. Use of copper internal pipes;
10. Chemical action;
11. Mechanical action;
12. Softening effect of distilled water upon iron;
13. Absence of air in water repeatedly condensed;
14. Too much blowing;
15. Decomposition of water, etc.

One of the worst things that can happen to a boiler is to have it fired at irregular intervals, hot for a time, then cold, as is the case with some heating-boilers, and also those in fire-engines. The amount of corrosion in some instances of the above kinds of treatment may be considerable.

In the larger cities fire-engines are kept under steam continuously, and while providing steam pressure at the moment they go to a fire, the results are also exceedingly more favorable to a longer life to the boiler than if they were irregularly fired.

Extensive internal corrosion frequently occurs in boilers using water that has been passed through surface condensers over and over again.

To prevent the corrosion add sufficient soda to the feed-water to make the water in the boiler alkaline, and place rolled-zinc plates in good metallic and electrical connection with the inside of the boiler and under water, so that no part of the boiler is more than 6 feet from the zinc, and renew the zinc when it is wasted.

To prevent corrosion in idle boilers fill them with water in which about 50 pounds of common soda has been dissolved to each 100 cubic feet of water. If the water is sufficiently alkaline after this is done, a bright nail hung in the water will not rust.

The French navy uses this system: The boilers are first completely filled with sufficient water and a solution of milk of lime or soda is added to the water. The solution is made stronger if the tubes are large, and of less strength if they are small, in order to avoid any danger of contracting the effective area by deposit from the solution.

The outside of the steel or iron tubes is painted with red lead or tar as far as the parts are accessible. For those parts which are inaccessible a protective coating is obtained by burning tar under them.

In the American navy boilers not in use are thoroughly cleaned and painted with a mineral oil.

In the English navy, after cleaning, boilers are thoroughly dried and a pan of charcoal burned in them to consume the oxygen of the air, and quicklime is used to absorb any moisture that may remain.

To prevent rust in unused boilers, it is advisable to keep them filled with water and the exterior well painted.

Corrosion of Iron and Steel.—Corrosion of iron and steel has been the subject of investigation of several Admiralty committees. This extract from their report, as made by Mr. Thos. Turner,* is to the point:

The differences of opinion on this subject have arisen, the author believes, on account of conclusions being drawn from limited observation or special circumstances, while much confusion has arisen from failing to recognize that the conditions in fresh water, salt water, the interior of the boiler, or in diluted acids are all different, and that a specimen which may very successfully resist corrosion in one of these cases may readily oxidize in another.

On account of the greater uniformity in the physical properties of steel, and the laminated character of iron, it was anticipated in the early days of the use of mild steel that it would resist corrosion much better than wrought iron. Thus Sir L. Bell † expressed the opinion that the cinder in wrought-iron rails would set up galvanic currents and thus lead to more rapid corrosion. Experience has, however, shown that on lines where there is very little traffic and the chief agent of destruction is corrosion, wrought-iron rails wear better than steel.

The result of the experiments of the Admiralty committees, which were appointed to consider the causes of the deterioration of boilers, and which issued reports in 1877 and 1880, led to the conclusion that in all cases wrought iron resisted corrosion better than steel.

Where the conditions were not severe the differences observed were not great, but where the plates were daily dipped in water and exposed during the rest of the time to the action of the atmos-

* Rowan, Steam Boilers, pp. 326, 327

† Jour. Iron and Steel Inst., Vol. I, 1878, p. 97.

phere, the superiority of iron was very marked, while common iron was less affected by corrosion than best Yorkshire iron, which is in accordance with the statement of Gmelin, that phosphorus diminishes corrosion in iron. The following percentages in favor of iron were obtained in these experiments:

Common iron resisted corrosion better than Yorkshire iron	9.6 per cent
Yorkshire iron resisted corrosion better than mild steel	16.0 " "

In another series of experiments, conducted by Mr. D. Phillips, in Cardigan Bay, and lasting for seven years, it was found that the average corrosion of mild steel during the whole period was 126 per cent more than wrought iron.*

Independent experiments conducted by Mr. T. Andrews † also showed that wrought iron corroded less rapidly than mild steel when the cleaned metallic surfaces were exposed to the action of sea-water.

The conclusions of the Admiralty Committee and of Mr. Phillips aroused much adverse criticism, and it was shown that though steel is more affected by ordinary atmospheric corrosion, it is not usually more affected when in the form of a steel boiler.

This was stated by Mr. W. Parker,‡ who based his conclusions on the result of over 1100 actual examinations of boilers, and his observations were confirmed by experienced makers and users of boilers, who took part in the discussion of his paper.

Sir W. Siemens says as manganese in mild steel is increased the tendency to corrode becomes greater.

G. J. Snelus has ascribed the pitting in steel to the irregular distribution of manganese in the metal.

Mallet says the alloys of potassium, sodium, barium, aluminum, manganese, silver, platinum, antimony, and arsenic with iron corrode more rapidly than pure iron; while the presence of nickel, cobalt, tin, copper, mercury, and chromium affords protection, the effect being in each case in the order given.

The reasons usually given for the corrosion of boiler-tubes are:

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* Inst. C. E., Vol. 65, 73; Inst. Mar. Eng., May 1890.

† Inst. C. E., Vol. 77, p. 323; Vol. 82, p. 281.

‡ Jour. Iron and Steel Inst., Vol. I, 1881, p. 39.

1. Fatty acids, from decomposition of animal or vegetable oils;
2. Hydrochloric acid, due to decomposition of $MgCl_2$ in sea-water at high temperature;
3. Galvanic action;
4. Use of salt;
5. Presence of carbonic acid in water.

Com. Walter F. Worthington * says: "Direct experiments have shown that under certain conditions it is possible to decompose magnesium chloride ($MgCl_2$) at a temperature of 212° F., setting free hydrochloric acid (HCl). When such action takes place it appears that the HCl is always immediately appropriated by some base other than the boiler metal."

Mr. Worthington has often searched for but never discovered any acidity by testing the water with litmus paper, nor met any other engineer who had found acid in our (U. S.) naval boilers. Lewis states that "chloride of iron is not found in the water of the boiler, which would be the case if any corrosion or pitting were due to the action of free hydrochloric acid." Then, again, our naval boilers are not under steam on an average of more than one-third of their time, and no HCl can be generated when the water is cold. The usual practice is to fill all boilers with fresh water at the start, and to use only about half of the boilers for steaming, the others serving as fresh-water tanks. In this way but a small part of the make-up feed is taken from the sea.

We may conclude that little if any damage is done to our tubes by the decomposition of the $MgCl_2$ in sea-water.

Boiler Corrosion from Rain-water.—Trans. Soc. of Steam-users of Paris † contains an account of the destructive corrosion of a steam-boiler which had been fed with rain-water collected from a zinc roof over a shop located in a district in which the atmosphere was heavily charged with acid vapors.

While pure rain-water itself, as we know, frequently produces serious corrosion, it appears that in this instance the water became acidulated through absorption of the acid fumes, and not only attacked the metal roof, but also the boiler, and to such an extent as to cause it to be condemned.

* Journal of the A. S. Nav. Engrs., Vol. 12, p. 589.

† R.R. Gazette, 1893, p. 771.

Chemical analysis of the water showed it to contain a considerable percentage of sulphuric acid.

Sulphuric and muriatic acids in carboys were driven to one factory on a road that was directly over a cistern to which all steam-drips were run; in some way a carboy broke at this point, and rather than be compelled to pay for the loss of the acid, the most of which went into the cistern and from there was pumped to the boiler, the man in charge told some plausible story other than the true one.

(From "The Locomotive," Hartford S. B. I. & I. Co.)

FIG. 8.—A Corroded Brace.

The corrosion shown in Figs. 8 and 9 was the result of this accident, and never again occurred in this factory from any cause.

The corrosive action was very intense at the rear end of the boiler: the plates and tubes began to pit badly, and rivet-heads and submerged braces wasted away rapidly.

The boiler-head, Figs. 10 and 11, was from one of a battery of boilers at a coal-mine in the West.

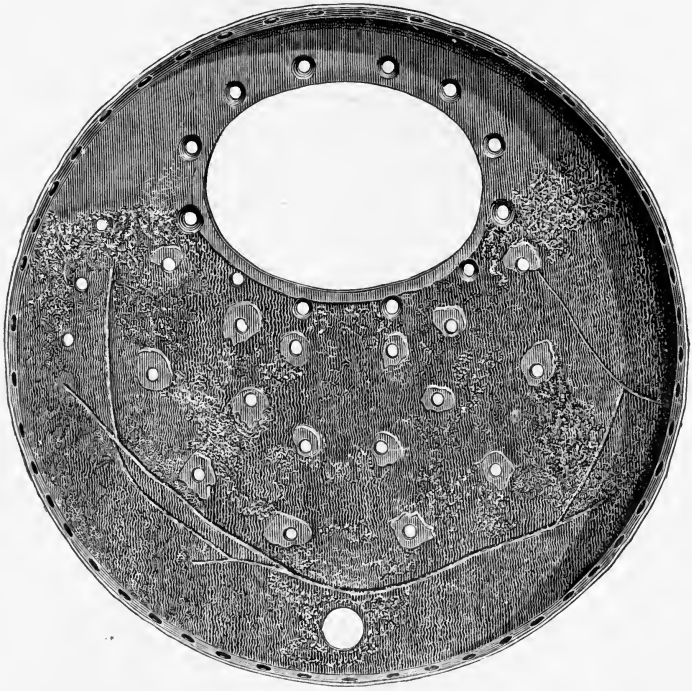
Contrary to advice, water impregnated with the products of the mine was fed to the boilers; the severe corrosion resulting is credited to the sulphur the water contained.

(From "The Locomotive," Hartford S. B. I. & I. Co.)

FIG. 9.—A Corroded Rivet.

In some places the corrosion was three-fifths the thickness of the head, originally $\frac{5}{16}$ inch. The life of the boiler was eight months. Where the braces were attached there

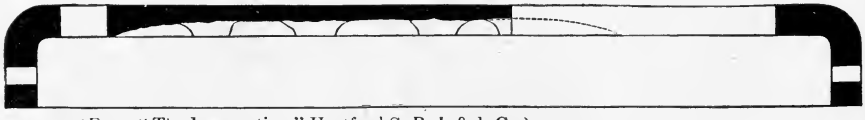
was no corrosive action. The cause of the lines shown, $\frac{1}{4}$ inch wide, $\frac{1}{16}$ inch deep, has not been satisfactorily explained.



(From "The Locomotive," Hartford S. B. I. & I. Co.)

FIG. 10.—Corroded Boiler-head.

Feed-water taken from a presumably reliable source may, while giving good results, change "without notice" as to quality

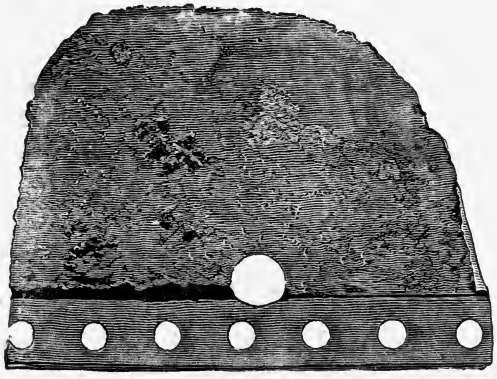


(From "The Locomotive," Hartford S. B. I. & I. Co.)

FIG. 11.—Corroded Boiler-head.

and do great harm unless closely watched, as in one case where the water was taken from a rock-bottom well fed by a spring, with which water the shell of the boiler was free from pitting or corrosion. After a sewer had been built in the neighborhood and

cut off the spring-water supply, the surface drainage, including cesspool and other contaminated waters, was the source of supply, resulting in the grooved and pitted plate Fig. 12.



(From "The Locomotive," Hartford S. B. I. & I. Co.)

FIG. 12.—Grooved and Pitted Plate.

The carbonate of ammonia produced by fermentation of urine in outhouses is a particularly destructive substance when it gets into feed-water.

The Corrosive Action of Chloride of Magnesium is well known.

H. Ost prepared a paper on this subject * which has been condensed and appeared in *Engineering*, from which this review is taken.

It has been assumed that magnesium chloride attacks the iron of boilers because it splits off hydrochloric acid. Ost contradicts this, and his experiments appear to be fairly conclusive. The question is interesting to the engineer, because magnesium salts appear in many boiler-waters, and in large quantities in sea-water. A. Wagner in 1875 conducted some experiments on the action of various salts contained in the feed-water for boilers, and working at ordinary atmospheric pressure, he observed that the iron rusted in the presence of the chlorides of the alkalies and alkaline earths when the air had access.

When air was excluded only magnesium chloride attacked the

* Chemiker-Zeitung.

iron. The corrosion was not well understood then, and was conveniently ascribed to some catalytic action. The chloride of magnesium was later thought to be decomposed in boiling water, but not unless it is present as hydrate, $MgCl_2.6H_2O$, and the temperature above 223° F.

Ost has only experimented in closed vessels, so as not to be troubled by ordinary oxidation. Water in which some magnesium chloride was dissolved, when distilled from glass vessels, was always found to be neutral and free from chlorine. The distillate also remained neutral when copper or tinned copper boilers were used for the distillation, at a pressure of several atmospheres; but some decomposition took place in these cases, for a certain amount of tin or copper was dissolved by the water. Ost then had a small experimental boiler specially constructed in Krupp's works, at Essen. It is a horizontal cylinder with hollow bottom, pressed out of a block of Siemens-Martin steel, and closed in front by a flange and a steel plate, packed with lead. The capacity of the boiler is nearly three quarts, and it was generally charged with two quarts of water, and the heating by gas-burners continued until one quart of the water had evaporated. The temperature was 360° F., corresponding to a pressure of about 10 atmospheres. After each experiment the inside of the boiler was found to be coated with a black, adhesive crust of the iron oxide, Fe_3O_4, a mixture of oxide and protoxide. This oxidation Ost ascribes to a decomposition of water into hydrogen and oxygen, which takes place whenever the hot feed-water comes in contact with the bare iron. Ost does not refer to electrolysis; some might possibly occur. The water was charged with 10 per cent solutions of various salts. The generation of hydrogen was most energetic, as much as 7.5 cubic inches of hydrogen being found in a total quantity of 8.8 cubic inches of gas collected in the presence of calcium chloride, potassium chloride, and potassium sulphate. No iron was dissolved in these cases, however, except when magnesium chloride or magnesium sulphate was present; but the chloride of magnesium dissolved as much as 2.08 grains of iron per quart of the 10 per cent solution. Now, we do not understand how magnesium sulphate could split up so as to be acid, and no free acid was observed in the case of magnesium chloride either, although the steam pressure was high. In Ost's opinion, the attack

of the iron is primarily due to the decomposition of the water; the oxygen oxidizes the iron, and the magnesium salt reacts with the protoxide of iron so formed, with the result that some of the iron is dissolved, while magnesium hydrate is precipitated. This reaction takes place according to the formula

$$MgCl_2 + Fe(OH)_2 = FeCl_2 + Mg(OH)_2.$$

The sulphate of magnesium would react similarly. In neither case is the reaction complete, however; that is to say, the reaction does not proceed until all the magnesium salt has been transformed, but only until a certain quantity of magnesium hydrate has been formed. It then ceases until the magnesium hydrate is removed, or until the equilibrium is disturbed in some other manner.

"In support of this view, Ost treated iron with hot solutions of magnesium salts in glass vessels on a water-bath, where the temperature could not rise above the boiling-point. Similar experiments were conducted with various irons and steels obtained from the Krupp works, including nickel-steel, and also with flower-wire, and the finely divided iron employed in pharmacy. These all generated hydrogen, the finely divided iron most (as was to be expected), and the nickel-steel and weld-iron least. The more sulphur the iron contains, the more easily it will be attacked; silicon, phosphorus, manganese, and also carbon, seem to protect the iron to a certain extent; but this point appears to require further investigation. The behavior of the iron also changes with the steam pressure.

"Thus magnesium salts, and especially magnesium chloride, are injurious to boilers, though probably for different reasons than are generally assumed. There is a remedy, however. At higher pressures the magnesium chloride and calcium carbonate interact, forming calcium chloride (which does not attack the iron), magnesia (which falls out as mud), and carbonic acid (which escapes with the steam). The escape of carbonic-acid gas begins at low steam pressures; and though the reaction is never complete, it would appear from Ost's experiments in his boiler that a little carbonate of lime suffices to prevent the corrosion of the iron by magnesium salt; he estimates that we need only a quarter as much carbonate as we have magnesium chloride. The precipitated

magnesia does not swell the bulk of the scale in such cases, because an equivalent amount of the calcium salt is dissolved. Some of the rivers, whose contamination with magnesium chloride induced Ost to investigate the subject, contain a sufficient amount of carbonates and bicarbonates to render the water harmless as feed-water from this point of view, though we have to fear the formation of rust, owing to the decomposition of water by iron. In sea-water we have no natural carbonates as a remedy, and the detrimental action of the magnesium salts that are always present is therefore unchecked."

Stillman * says: Where all the chlorine is not in combination with the sodium and potassium, magnesium chloride is usually present.

This compound ($MgCl_2$), while not scale-forming, is considered as an active corrosive agent, upon the supposition that at the temperature of 100° C., and higher, it is decomposed and hydrochloric acid formed and liberated.

This analysis of water, from a driven well in Florida, is an illustration of this, and was complained of as causing an excessive amount of scale, and also the corrosive action was very marked.

	Grains per Gallon.
$NaCl$	18.83
KCl	3.91
$MgCl_2$	6.06
$CaSO_4$	11.49
$CaCO_3$	17.08
$MgCO_3$	8.40
SiO_2	0.64
Al_2O_3, Fe_2O_3	0.41
Organic	8.05

Corrosive Action of Water.—A Parsons steam-turbine in Silesia underwent but one repair in 7000 running hours; that was the reseating of the double-beat admission-valve, mainly due to unclean acid-holding water.

The relative corrosion of certain metals, taking wrought iron as 100, is thus given by H. M. Howe:

* Eng. Chemistry, p. 50.

Metal.	Sea-water.	Fresh Water.	Weather Exposure.	Average.
Wrought iron.	100	100	100	100
Soft steel.	114	94	103	103
3 per cent nickel-steel.	83	80	67	77
26 " " " "	32	32	30	31

Prof. Ernst Cohen,* Amsterdam, Holland, says that chemically pure copper is corroded only by sea-water if atmospheric air can co-operate in its action.

Tests made with electrolytic, sheet-hammered, cast, and commercial copper.

Copper is corroded if sea-water, air, and carbonic acid act on it simultaneously.

Condenser-tubes, 33.40 per cent zinc and 66.60 per cent copper, corrode only in the presence of carbonic acid and air.

Tin is corroded in the presence of sea-water and atmospheric air.

Oxide of copper and nickel resist even a prolonged action of sea-water and atmospheric air, while aluminum bronzes, though often recommended, are strongly attacked in a short time.

Ordinary steel castings when placed in sea-water in contact with nickel-steel result in bad corrosion of the ordinary steel.

Corrosion by Sea-water.—Pieces of iron low in phosphorus in contact with iron high in phosphorus showed that that low in phosphorus formed the anode and was badly corroded, and the other formed the cathode and was protected from corrosion.

Herr Diegel suggests the use of certain alloys rather than copper pipes, after tests with alloys of copper with iron, zinc, nickel, and aluminum, the copper-nickel alloys being 18 to 42 per cent nickel.

Rods of these alloys suspended in salt water for twenty-five months showed results most favorable to the copper-nickel alloys.

The water action was largely influenced by the metals alloyed with the copper, for the iron-bronze was deeply corroded, while the nickel alloy was protected. Chemical analysis showed that " pure copper " is, in general, more rapidly corroded than metal containing impurities, the ordinary commercial material being acted upon less rapidly than electrolytic copper.

* Inst. Nav. Arch., Vol. 44, p. 215.

The presence of oxide in copper increases its liability to corrosion. Apparently the presence of arsenic in copper hastens the corrosive action. Where oxidation has occurred, arsenic seems to retard corrosion.

Attaching pieces of zinc to copper pipes is the usual method employed to prevent corrosion, as it serves the purpose of an anode to the copper, and itself is corroded by the galvanic action set up.

Where pieces of corroded zinc fall on copper pipes and remain, excessive corrosion of the copper is produced, and hence we have an objection to its use. Herr Diegel speaks of the large variety of effects from an equally large number of causes, as a result of using copper pipes on shipboard.

In some cases there is pitting over the whole inside surface of the pipes, while in others limited local corrosion is seen as cutting and grooving.

This action seems to be caused by high heating when brazing on flange-fittings.

This local corrosion may come from

1. Variety in copper;
2. Air in the pipes;
3. Electrolytic action.

The rate of corrosion in alloys seems to be governed by their relative position in the galvanic scale; metals which resisted corrosion well when in contact with metals electro-negative towards them corroded badly when in contact with electro-positive metal. Electrolytic copper, 99.955 per cent pure, in sea-water with ordinary commercial copper, 98.98 per cent pure, with 0.6 per cent arsenic, was corroded rapidly, fully thirteen times as fast as the commercial copper.

Two ships' hulls, the one sheathed with the pure, the other with the impure copper, gave similar results, so that the cause was not in any galvanic action.

A sheet of pure copper oxidized in spots was immersed and the bare portions rapidly corroded, showing a galvanic couple in the sheet itself, the pure copper being the anode.

Annealed copper corroded less rapidly than hard-drawn copper of a higher resistance and elastic limit.

All of these results were obtained after tests lasting 2 to 2½ years had been completed.*

Action of Sea-water on Cast Iron.—W. H. Thorpe, in *Engineering*, 1905, gives his experience with 45 cast-iron piles:

"In no case was there any general softening of the whole thickness, but merely a distinct change for some definite thickness inward. It was most marked close to the ground and generally disappeared at a height of 5 feet. Different piles in the same structure did not show the same amount of softening. The injured material taken from a pile thirty-six years old was soft, greasy, and black, but after exposure to the air for a few hours became a dry yellow powder."

Corrosion.—Boiler-tubes corroded by forcing air through tubes wetted by distilled water showed a loss in weight in sixteen weeks of 0.315 grain per square inch, while when the water was made alkaline the loss was reduced to 0.1 grain.†

Method of Testing Water for Corrosiveness.—For marine practice, where engineers and firemen are off shore a long time, it is well to know how to test the feed-water one is using, and for this purpose there is no better guide than the method of testing for corrosiveness as given by the Babcock & Wilcox Company in *Marine Steam*, from which the following is taken with their permission:

"The first thing in testing, as is well known, is to see that the color of the water, as shown in the gauge-glass, is neither black nor red. The only color admissible is slightly dirty gray or straw color, unless the water is transparent. So long as water is red or black, corrosion is going on, and it must immediately be neutralized by freely using lime or soda, and frequently scumming and blowing off, the make-up being provided by the evaporator.

"The salinometer is not a very accurate instrument for determining the quantity of sea-water in boiler-water, but the apparatus here described gives a convenient and accurate method of ascertaining the exact number of grains of chlorine per gallon in the water tested. It is based on the scheme for the volumetric determination of chlorine devised by Fr. Mohr, an eminent chemist, and requires one graduated bottle, one bottle of silver solution con-

* Eng. News, Vol. 50, p. 173. † Eng. Rec., Vol. 51, p. 187.

taining 4.738 grams of silver nitrate to 1000 grams of distilled water, and one bottle of chromate indicator, which is a 10 per cent solution of pure neutral potassium chromate.

"*To Make Test.*—Fill the graduated bottle to the zero-mark with the water to be tested; add one drop of the chromate indicator, then solwly add the silver solution; keep shaking the bottle. On nearing the full amount of silver solution required the water will turn red for a moment and then back to yellow again when shaken. The moment it turns red and remains red, stop adding the silver. The reading on the graduated bottle at the level of the liquid will then show the amount of chlorine in grains per gallon. For example, if a permanent red color is shown when the level is midway between 150 and 200 there are 175 grains of chlorine per gallon.

FIG. 13.
Graduated Bottle.

"The principle of the process depends upon the fact that if some of this silver solution be dropped into water containing a chloride, a curdy white precipitate of chloride of silver will be formed. If there is also present in the water enough potassium chromate to give a yellow color, the white precipitate will continue to perform as before, owing to the silver having a greater affinity for chlorine than for the chromic acid in the chromate. But, at the moment when all the chlorine in the sample has been converted, the silver will attack the yellow potassium chromate, and chromate of silver will be formed, which is red in color. The amount of chlorine present is, therefore, shown by the amount of silver solution required to convert it all to silver chloride, and the determination of the exact point at which the chloride precipitate ceases to form is greatly facilitated by observing when the chromate indicator turns from yellow to red.

"It is not necessary to add the silver solution until the color becomes very red, as the delicacy of the reaction would be destroyed, but the change from yellow to yellowish red must be

distinct and must not change on shaking. The sample of water to be tested should be neutral, as free acids dissolve the silver chromate. If it should be acid, neutralize by adding sodium carbonate. Slight alkalinity does not interfere with the reaction, but should the example be very alkaline, it may be neutralized with nitric acid.

"Should it happen that the color does not change within the limits of the graduations, the sample may be tested by diluting with distilled water. For example, add three parts of distilled water to one part of the sample. If, then, on testing the mixture, the color changes at 200, the number of grains per gallon in the original sample will be four times this reading, or 800 grains.

"The chlorine should be kept down to the least possible amount —say below 50 grains per gallon—as the nearer the boiler-water is to fresh water the safer the boilers are against corrosion.

"If the water is so corrosive as to be acid, blue litmus paper which has not been allowed to become deteriorated through exposure to the atmosphere (keep in a bottle with a glass stopper) will turn slightly red. If a change in color is not apparent at once, it should be allowed to remain in the solution a few minutes and then carefully dried and compared with an unused sample.

"Another method is to put into it a few drops of a chemical called methyl-orange. This methyl-orange gives a yellow color so long as the water is alkaline, but if turned pink it shows that the water is acid and therefore highly corrosive. This latter test is more sensitive than the litmus-paper test and should be used in preference.

"A testing-kit containing the graduated bottle and the solutions referred to, also strips of blue and red litmus paper, neatly packed in a padded box, is supplied by the Babcock & Wilcox Company with all boiler installations intended for salt-water service."

A Peculiar Example of Scale Formation Following Corrosion is given by a boiler in one of the small vessels in the U. S. Navy after several months' experience on the Cuban blockade in 1898, during the Spanish-American war.

The boiler in question was a Yarrow boiler, consisting of a steam-drum to which are attached two banks of straight tubes, one of which extends obliquely down on either side of the grate. The upper ends were expanded into the steam-drum, the lower

ends expanded into a practically flat plate, forming the top or cover of a water-chamber or mud-drum.

The tubes were 1-inch-diameter copper tubes, very closely set and staggered.

When repairs were made the tubes were found to be considerably pitted and corroded on the exterior, and, in some cases, entirely eaten through and away. In the case of one tube 5 inches of its length was gone and the free ends were as thin as paper.

Unaware of these conditions, the engineer steamed into port with a steam pressure of 250 pounds per square inch in the boilers.

The spaces between tubes were solid with hard scale at the above break, and no leakage was noticed.

Marine boilers of this class are supposed to use only fresh water from distilling apparatus aboard ship, but frequently sea-water must be used, the sea-salt accumulating on the tubes resulting in overheating or burning. Then cracks sometimes show themselves, and the salt water mingles with the soot and ashes, and further leaks cannot be seen readily at the point of rupture, and at the same time corrosion is encouraged and is progressing more rapidily

In this case the wasted tube was not scaled on its interior, all of its troubles coming from the outside.*

The testimony taken by the United States inspectors of steam-vessels showed that, on the night of September 12, 1899, the regular engineer closed the connections between the gauge-glass and the boiler, as was his custom, and that the next day, being sick, he employed another engineer to take his place for the day. Also that the tug left her berth shortly before 7 o'clock in the morning in charge of the substitute engineer, and that the accident occurred about 1 o'clock, while the tug was towing a large loaded scow against the tide. The day after the accident, the gauge-glass was noticed to have 3 or 4 inches of water and the boiler connections were closed.

The substitute engineer testified that the boiler-gauge showed a steam pressure of 140 pounds while towing the scow, and everything appeared to be all right until he noticed that the pressure

* Cassier's Mag., Vol. 16, p. 620.

was falling. He then shoveled on fresh coal and turned the exhaust into the stack. Receiving a signal to slow down, he attempted to work the injector, but could not get water into the boiler, so was forced to draw the fire. While drawing the fire the tubes dropped down, but without explosion or any apparent commotion. The superintendent of the dredging company testified that he visited the tugboat an hour and a quarter after the accident, and found the fire-room still so hot that he could scarcely endure the heat.

When it is remembered that the fiercest heat of the forge is required to bring wrought iron to the plastic condition necessary for welding, and that a still higher temperature is required for melting it, some idea is gained of the extreme temperature that must have prevailed.

An examination of the boiler-tubes showed that they were all clear, and that the circulation was not impeded; also that the tubes were coated on the inside and outside with black oxide of iron, which is formed by the combination of iron with oxygen gas when the former is red-hot. The combination will take place in the presence of air or aqueous vapor; so it is believed by the manufacturers of the Boyer sectional water-tube boiler, who made the boiler in question, that the condition of the tubes shows conclusively that, by reason of the connections between the boiler and the gauge-glass being closed, the engineer did not know where his water-level was, and that it had been materially lowered during the hour and a half while lying still before towing the large scow; also that the towing of the big loaded scow against the tide was hard work for the little boat, and that there was an unusual consumption of water. Thus the upper evaporating-tubes became empty of water, and when the exhaust was put into the stack they became superheated and then red-hot, at which time the steam was decomposed into oxygen and hydrogen gases. These gases being released by a split in some of the pipes, part of the oxygen combined with the iron, forming black oxide of iron, and leaving the hydrogen to combine with the oxygen of the air passing through the furnace. Thus with the aid of the fire the terrific heat was produced that melted the boiler-tubes. This action was further aided by the air that passed over the fire, the boiler-doors being open at the time, and the engineer engaged in hauling the fire.

That the collapse of the furnace did not produce a disastrous explosion, with a consequent loss of life and property, is a remarkable fact and one that testifies to the safety of the water-tube boiler when subjected to the roughtest usage. The damage was entirely confined to the nest of tubes. Fig. 14 shows the boiler before the outside tubes were removed, and Fig. 15 shows its appearance after four rows were taken off.*

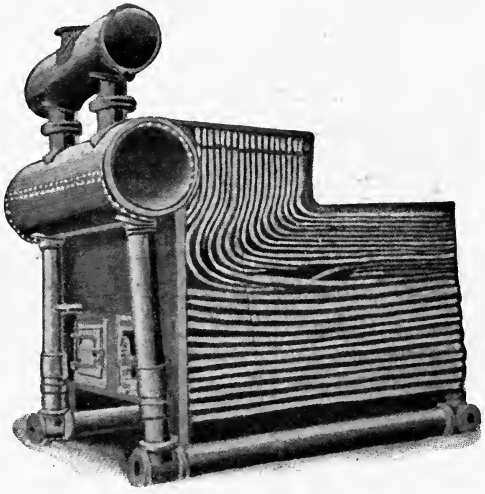


FIG. 14.—An Exploded Boiler. (A marine accident.)

A Remarkable Example of Boiler Destruction, where flues were clear of scale and the accident due to the sudden formation of magnetic oxide of iron, was that of the water-tube boiler on the tugboat W. H. Beard, 28½ gross tons, used in towing mud-scows, which boiler was so badly burned that 300 of 785 water-tubes were practically melted together.

Fig. 16 is of a tube corroded by pure water coming in direct contact with the iron; this forms a blister, underneath which pitting goes on to considerable depth. A heavy fall of snow melting quickly on a large watershed is sure to give a very pure water to the rivers draining the same, and if feed-water is pumped from the river containing frequently less than one part of solid matter to 100,000, and used in a boiler which has no scale veneer, bad

* Steam Engineering.

corrosion is certain, and has caused endless trouble, the corrosion being principally due to the free CO_2 contained in the water.

Lime introduced in small quantities from time to time is the proper thing to maintain this thin scale, if such water is used for any length of time.

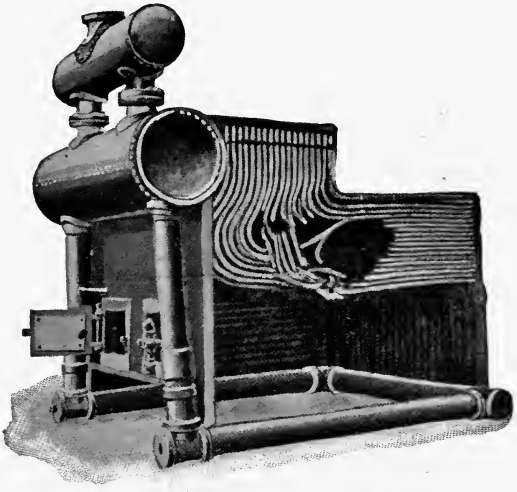
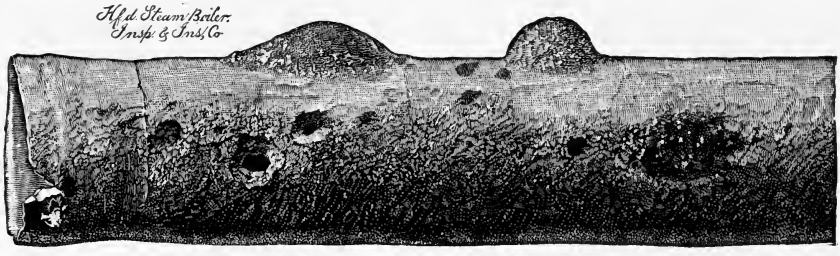


FIG. 15.—Another View of an Exploded Boiler.



(From "The Locomotive.")

FIG. 16.—Tube Pitted by Pure Water.

Salt Water as Feed-water.—*Power* * quotes a marine engineer who says that salt water could be used in boilers without trouble. The boilers should not be blown down until the water in the boilers has the saline part increased four times; the water should then

* Nov. 1903.

be all let out, and 100 pounds of soda put in at the top of the boilers. It should also be fed during the run.

In the Philippines, where the water is the densest in the world, he had no trouble with the boilers. While he does not advise blowing down such boilers daily, he thinks where they can be cooled down and the water changed once in two weeks the water can be used.

Analysis of waters, if studied carefully, may often reveal corrosive effect from the action of heat on the water when in the steam-boiler. The following tables* give the reactions by which hydrochloric, sulphuric, and nitric acids may be formed in boilers:

a. Formation of Hydrochloric Acid.

Chloride of magnesium and steam...	$MgCl_2 + H_2O = MgO + 2HCl.$
Sulphate of magnesium and alkaline chlorides.....	$MgSO_4 + H_2O + 2NaCl = Na_2SO_4 + MgO + 2HCl.$
Silica and alkaline chlorides.....	$SiO_2 + 2NaCl + H_2O = Na_2SiO_3 + 2HCl.$
Ferric chloride.....	$Fe_2Cl_6 + 3H_2O = Fe_2O_3 + 6HCl.$
Ferrous chloride.....	$3FeCl_2 + 4H_2O = Fe_3O_4 + H_2 + 6HCl.$
Carbonate of magnesium and chlorides	$MgCO_3 + 2NaCl + H_2O = Na_2CO_3 + MgO + 2HCl.$
Chloride of ammonium.....	$NH_4Cl = NH_3 + HCl.$

b. Formation of Sulphuric Acid.

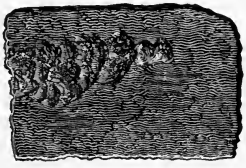
Normal ferric sulphate.....	$2Fe_2(SO_4)_3 = (Fe_2O_3)_2SO_2 + 5SO_3.$
Ferrous sulphate.....	$3FeSO_4 + 4H_2O = Fe_3O_4 + 2H + 2H_2SO_4$
Sulphurous acid, sulphite.....	$SO_2 + H_2O + O = H_2SO_4.$
Sulphurous acid and ferric sulphate..	$H_2SO_3 + Fe_2(SO_4)_3 + H_2O = 2FeSO_4 + 2H_2SO_4.$
Sulphurous acid and ferric chloride..	$SO_2 + Fe_2Cl_6 + 2H_2O = 2FeCl_2 + 2HCl + H_2SO_4.$
Sulphuretted hydrogen, sulphides...	$H_2S + 4O = H_2SO_4.$
Sulphate of calcium and organic matters.....	$2CaSO_4 + C + 3H_2O = Ca(OH)_2 + CO + 2H_2SO_4.$
Sulphate of aluminium.....	$Al_2(SO_4)_3 + 3H_2O = Al_2O_3 + 3H_2SO_4.$
Sulphate of ammonium.....	$(NH_4)_2SO_4 = 2NH_3 + H_2SO_4.$
Sulphate of copper	$CuSO_4 + Fe = FeSO_4 + Cu.$

* De la Coux, p. 101.

c. Formation of Nitric Acid.

Normal ferric nitrate	$Fe_2(NO_3)_6 = \text{Ferric nitrate} + HNO_3$.
Alkaline nitrate and acid sulphate or sulphuric acid	$NaNO_3 + NaHSO_4 = Na_2SO_4 + HNO_3$.
Nitrate of ammonium	$NH_3NO_3 = NH_3 + HNO_3$.

Tannin when used with a certain water as a solvent for scale gave no trouble, but when the regular feed-water was left to itself, or certain patented compounds were used, the effect was something like the scale shown in Fig. 17, under which conditions corrosion acted rapidly, in fact but a few months sufficed to eat through the plate.



(From "The Locomotive.")

Fig. 17.
Result of Corrosion.

In another case a patch lasted only twelve months, the corrosive action destroying it being due to the presence of ammonia in some form, probably sal-ammoniac, which if at all concentrated forms a very active agent in the destruction of steel plates.

Note.—For a very complete digest of boiler corrosion, mechanical in character rather than from water, see Engineering News, Vol. 37, p. 94, and full inset plate.

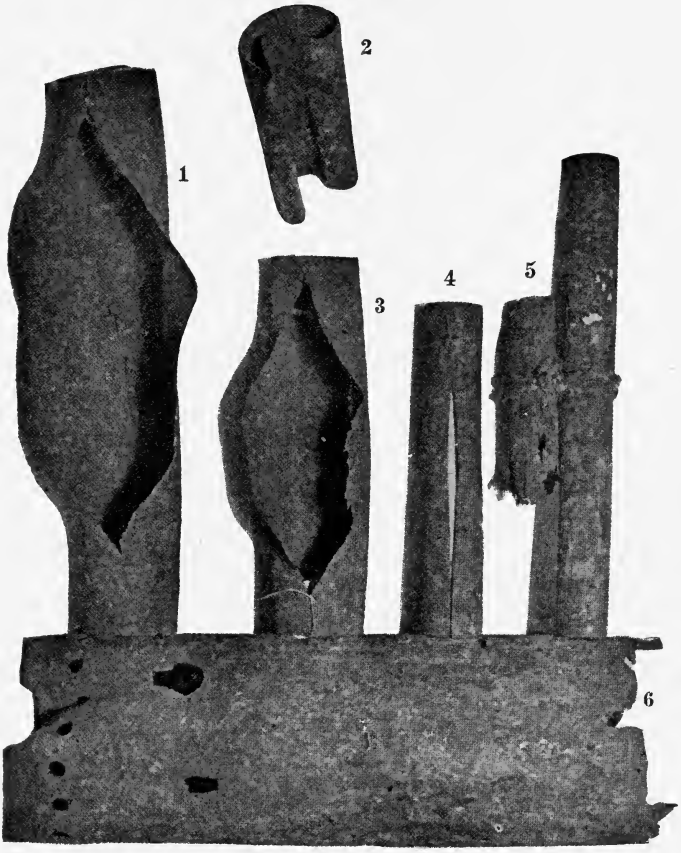
Tests by W. F. Worthington to discover the difference in corrodibility of tubes made of iron and Bessemer or open-hearth steel resulted as follows:

1. Corrosion was quickly present in all samples in pure water;
2. Though a jet of air struck the center of the inner side of each sample, in many cases the outer side was much corroded;
3. All test-pieces show pitting to a certain extent, which agrees with Rowan's statement, that "pitting occurs in all kinds of corrosive liquids and all kinds of metals, even platinum."
4. The corrosion attacked the seamless-drawn tubes $\frac{1}{16}$ inch in depth and then shelled off, leaving metal bright.
5. Oxygen attacked 30 per cent nickel-steel with avidity, notwithstanding Vossmaer says 25 per cent nickel-steel is practically incorrodible.

The above writer cannot conclude from his experience which tubes are the best. He says there is reason to believe that at 356° F. (146 pounds pressure) iron or ordinary carbon steel begins to decompose water.

Nickel-steel seems to be the only available material.

Trautwine says: "It is said that the softest water may be kept in brass vessels without any deleterious results.



(Fidelity & Casualty Co.)

FIG. 18.—Nos. 1 and 3, Ruptured Tubes; No. 2, Collapsed Tube; 4, Split Feed-pipe; 5, Corroded Tubes. No. 6 was taken from a water-tube boiler and carried 100 pounds of steam up to the time inspection was made. Accumulation of scale inside prevented its leaking.

"Copper and bronze are very little affected by sea-water.

"Fresh water corrodes wrought iron more rapidly than it does cast iron; the reverse seems to be true with sea-water.

"Corrosion of iron or steel by sea-water increases with the carbon in the metal.

"Iron boilers made fifty or sixty years ago are still doing good work."

Percy, in a paper, "British Assoc. Rep. 2," 1849, pp. 39, 40, on copper containing phosphorus with details of experiments on the corrosive action of sea-water on some varieties of copper, describes an alloy containing copper, 95.72 per cent; iron, 2.41 per cent; phosphorus, 2.41 per cent, which on being exposed to sea-water for nine months suffered no loss of weight.

Corrosion of Iron and Steel Tubes.*—The experience of the Mutual Boiler Insurance Company with a large number of small upright boilers, in which one new heavy steel tube with fusible plug replaced one of an all-iron set, was as follows:

At the end of a few years the steel tubes were pitted and corroded, the iron tubes being as good as ever. A horizontal boiler containing both iron and steel tubes, run at high pressure, gave equally good results for both metals.

The steel tubes gave poor service in heating-boilers run at low pressures and laid off a part of the year.

A serious case of corrosion of a feed-pipe and the shell of a horizontal tubular boiler between the water-line and above the fire-line was caused by the return from copper vacuum-kettles of the condensed steam used in heating them and to which a little raw water was to be added. While in ordinary corrosion cases the trouble is localized, in this case the trouble was evenly distributed all over the pipe. The particles of the copper coming over from the kettles was the probable cause of the corrosion.

Mr. Yarrow gives as the probable causes of the deterioration of marine boiler-tubes:

"1st. The action of acids in the water due to the grease, which in spite of every precaution finds its way into the boiler.

"2d. The tubes become overheated and oxidizing on the outside through contact with hot gases when passing from the furnace to the uptake.

"3d. The action of the steam, which if superheated decomposes, causing deterioration on the inside of the tubes.

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* Eng. News, Vol. 50, p. 318.

"The last two conditions occur when the tubes from defective circulation, shortness of water, or from the collection of scale become overheated."

The chemical composition of the feed-water plays an important part in each of the above cases.

In order to show the relative deterioration due to the action of acids in the water on boiler-tubes, Yarrow tested two mild steel tubes and two 25 per cent nickel tubes for corrosion. After being immersed for $22\frac{1}{5}$ days in a bath of 33 per cent hydrochloric acid the results were as per table.

Fig. 19 shows how the carbon-steel tubes *B* and *F* and nickel-steel tubes *A* and *E* looked after the completion of the tests. The same figure shows results of fire-tests of similar tubes and is self-explanatory.

CORROSION TEST.* EXPERIMENTS TO ASCERTAIN THE EFFECTS OF ACID ON NICKEL-STEEL AND MILD CARBON-STEEL TUBES.

Kind of Steel.	Original Weight in Grams.	Solution Used: Two Parts of Water to One Part Concentrated Hydrochloric Acid. Weight in Grams at End of Each Period of Immersion.									Total Hours.	Total Loss in 533 Hours, or 22 Days 5 Hours.	
		21 Hrs.	64 Hrs.	44 Hrs.	92 Hrs.	168 Hrs.	72 Hrs.	24 Hrs.	24 Hrs.	24 Hrs.		In Grms.	In Per Cent.
Nickel . .	190	190	189	189	188	186	186	185	185	185	533	5	2.63
Carbon. .	186	184	173	166	140	101	98	94	91	88	533	98	52.68
Nickel . .	188	188	187	187	186	183	182	181	181	181	533	7	3.72
Carbon. .	188	187	173	162	137	112	95	92	90	88	533	100	53.19

* Colby, Soc. Nav. Engrs., 1903.

For corrosion and pitting Mr. J. T. Fennell recommends from experience thoroughly cleaning the shell and painting with a thin wash of Portland cement, and putting 3 pounds of sal soda in when starting the boiler, and $\frac{1}{2}$ pound of the same every few days. The result was very satisfactory.

The boats on the Mississippi River have "pans" in their boilers, about 4 feet long by 12 inches wide, made of sheet iron, with a small I bolt in each end 12 inches long to support them. These pans must be put in through the manhole above the flues and passed down between them to the front end, and being 2 inches deep, are made secure by placing them tight up against the

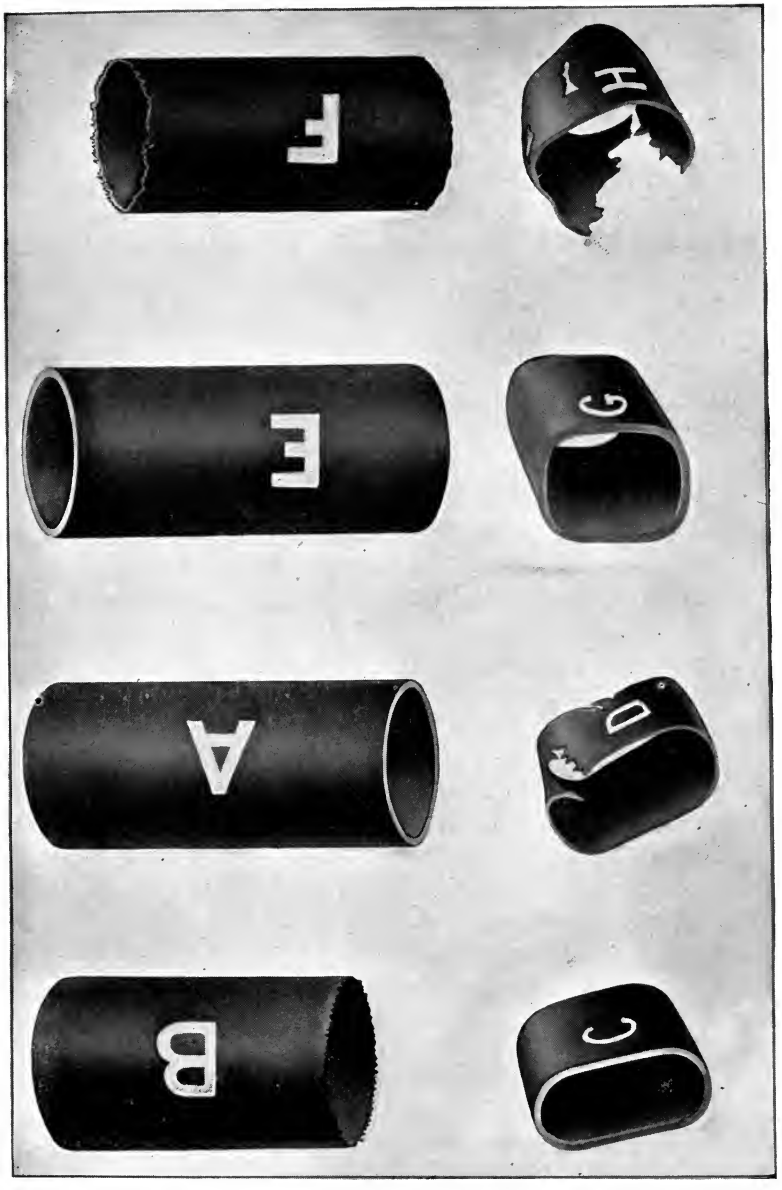


FIG. 19.—Corrosion of Steel Tubes. (From Paper by Albert Ladd Colby, A. S. Nav. Arch'ts, 1903.)

bottom flues, and directly over the fire, the back end being about 2½ inches over the forward mud-drum leg.

These pans catch a great deal of the loose scale that is brought up by circulation.

The end of the pan being over the mud-drum leg assists the scale being drawn from the pan directly to the leg when blowing out, which is done about five times every twenty-four hours.

For horizontal tubular boilers Mr. Fennell makes these pans 5 feet long by 2 inches deep, and of such a width as to get them through the manhole. Their bottoms should be square or flat, not arched. Arched bottoms are always a failure.

Pans in horizontal boilers should be kept at least 18 inches away from the front head. A weight made from a ladleful of lead, cooled, is used to hold the pan from the tendency to float.

Pitting.—Pitting is a most dangerous form of corrosion and "may be described as a series of small holes often running into each other, in lines and patches, eaten into the surface of the iron to a depth sometimes reaching one-fourth of an inch." The mysterious ways of pitting have been enigmas to engineers.

Grooving frequently occurs around the stay-bolts of the water-legs or furnaces of locomotive boilers, radiating also from the stay-bolts as centers. The side sheets bending backward and forward under varying steam pressure start incipient cracks or open up the surfaces to admit water. The repeated and intermittent strains on the sheets from the very severe conditions such boilers are called upon to meet aid very materially in this work of corrosion.

Idle boilers are especially liable to pitting and usually severe sufferers, unless the best of care is given them.

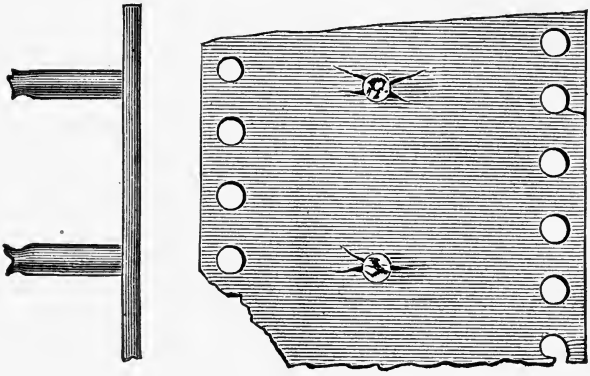
Fig. 20 is an example from an idle boiler in which impure water had been used, though similar results would have been obtained if pure water had been used; and though the exterior of the plate was clear, the furrows were quite deep inside, and stay-bolts were corroded entirely off.

Examples of pitting are shown in Figs. 21 and 22.

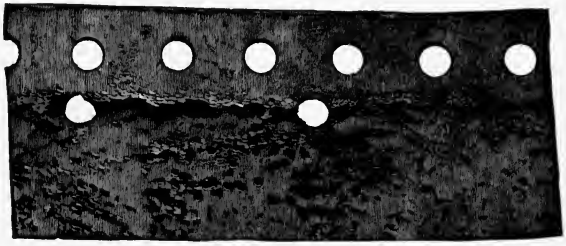
These examples are from a horizontal tubular boiler 48 inches in diameter and in use for six years at a nail-works.

The lap-joint shown was directly over the flue through which the waste furnace-gases were admitted to the boiler-setting, and

consequently were exposed to sudden and violent variations of temperature. One minute steam would blow off at 90 pounds



(From "The Locomotive," Hartford S. B. I. & I. Co.)
FIG. 20 —Corrosion around Stay-bolts.



(From "The Locomotive," Hartford S. B. I. & I. Co.)
FIG. 21.—A Pitted Plate—Outer Lap.

(From "The Locomotive," Hartford S B. I. & I. Co.)
FIG. 22.—A Pitted Plate—Inner Lap.

gauge pressure; the next the gauge was indicating a drop to 40 pounds.

As in almost every other case, the grooving and pitting was most severe along the edge of the lap.

The feed-water was very pure—so much so that there was no scale; had it been less pure, it would probably scale the shell sufficiently to prevent the pitting.

The experience of the Hartford Steam-boiler Inspection and Insurance Company is that some very troublesome cases of this character have been cured by curving the flue toward the rear end of the boiler (that is, the flue from the blast-furnace), so that the gases will not impinge directly on the plates, but be delivered horizontally along the under surface of the boiler.

Mud-drums which are located close to brick walls and are frequently supplied with cold water are very likely to "sweat"; this moisture, along with the lime of the setting, starts pitting; and as a similar action goes on in many cases inside of the drum also, it is but a short time when the pitting has perforated the shell. To prevent inside pitting, blow down the drum frequently; to stop outside troubles, keep the masonry away from the boiler-metal.

In recording the explosion of twenty-two two-cylinder steam-boilers at Friedenshütte, Germany, July 25, 1887, *Locomotive*, 1888, says: "The feed-water was, as is apt to be the case in coal districts, bad for boiler use. It made a bad scale which became detached and, falling to the bottom of the boilers, formed a deposit which caused some pitting of the shell-plates.

"This is the analysis of the feed-water used:

Silicic acid	.0300 gram
Iron oxide	.0160 "
Lime	.2624 "
Manganese oxide	.0540 "
Sulphuric acid	.3698 "
Chlorine	.0139 "
Organic matter	.1200 "

A French engineer, M. Olroy,* in *Engineering*, gives an interesting account of an investigation by him into the cause of pitting in boilers. He says: Pitting is particularly likely to occur if a water very free from lime is used in a clean boiler. The pits take the form of conical or, more frequently, spherical depressions, which are filled with a yellowish-brown deposit, consisting mainly of iron oxide.

* Locomotive, Nov. 1894.

The volume of the powder is greater than that of the metal oxidized, so that a blister is formed above the pit, which has a skin as thin as an egg-shell. This skin contains usually both iron oxide and lime salts, and differs greatly in toughness.

In many cases it is so friable that it breaks with the least shock, falling to powder, while in other cases the blister detaches itself from the plate as a whole. An analysis of the powder in the pits showed it to consist of 86.26 per cent of peroxide of iron, 6.29 per cent of grease and other organic matter, and 4.25 per cent of lime salts, the remainder being water, silica, aluminum, etc. The skin over the pits was found to contain 38 parts of calcium carbonate, 12.8 parts of calcium sulphate, and 32.2 parts of iron oxide, with about 8 parts each of magnesium carbonate and insoluble matter.

Feed-heaters often suffer badly from pitting, particularly near the cold-water inlet, and in boilers the parts most likely to be attacked are those where the circulation is bad, especially if such portions are also near the feed-inlet.

In locomotives the bottom of the barrel is most frequently attacked, and the largest ring.

The steam-spaces are generally free from pitting, unless the boiler is frequently kept standing with water in it. As the water evaporates, pitting is then likely to occur along the region of the water-line, a part which, in a working boiler, is generally free from attack. This is especially the case if longitudinal joints of the boiler are liable to be exposed by the evaporation of the water, and to form a ledge on which moisture can rest.

When a boiler forms one of a battery, and is kept standing for a long interval, the top of the boiler is liable to pit. Steam finds its way into it, and condenses on the roof, causing bad pitting there.

Perfectly pure water containing no air does no harm, and steam alone will not cause pitting, unless it gets a supply of air. The Loch Katrine water of Glasgow, which causes pitting in clean boilers, contains much gas.

MM. Scheurer-Kestner and Meunier-Dolfas inclosed a polished iron bar in a natural water containing much oxygen and no lime salts. The bar gradually rusted, but the corrosion ceased when the oxygen was used up. The bar was then removed, repolished, and put back, after which it remained perfectly bright.

Repeating the experiment with water containing lime, the rusting was much less complete, the lime salts forming a protective layer on the iron, but corrosion recommenced on polishing the layer off.

In distilled water the bar remained quite bright. The corrosion is much more rapid if the water contains carbonic-acid gas as well as oxygen. In this case a voltaic action takes place. The rust first formed is electropositive to the iron, which then dissolves away, decomposing the water. It is for this reason that in cases of pitting it is essential that all traces of the iron peroxide should be cleaned from the metal, or the rusting will be continued.

Parker, in the *American Machinist*, July 1892, says that in Louisville, Ky., rust and scale in boiler-shells and mud-drums has been prevented by a thorough cleaning and then applying graphited oil with a swab-brush or anything handy to the joints and parts where the water enters the drum. The operation is repeated every four or six weeks with the most gratifying results.

In a boiler of the porcupine type pitting was arrested by scraping and painting with graphite mixed with mineral oil.

A pair of new cylindrical boilers, 42 inches in diameter by 28 feet long, were tested for a period of six months. Feed-water was mine-water. They replaced others rotten from corrosion, and during this test the occasional application of plumbago and mineral cylinder-oil kept back corrosion. Mr. Deeley has found pitting to cease in many instances when the water was kept slightly alkaline.

The late Dr. R. H. Thurston, in a communication to *Engineering News*, 1898, gave, as the result of his researches in connection with this subject, these notes, which are also to be found in his "Materials of Engineering," Vol. 2:

1. Corrosion can ordinarily only occur in the presence, simultaneously, of oxygen, moisture, and carbon dioxide (Calvert).

2. The gases of the locomotive accelerate corrosion by their peculiar acid quality, arising from their contents of sulphur oxides; iron and steel absorbing acids somewhat greedily.

3. Cast iron, in dilute solutions of acids, is rapidly acted upon, especially in warm water—in the flow of water of condensation from engine-condensers, for example, losing the metal, and often leaving the carbon and other matters; the piece retaining its form

and general appearance unchanged, but with enormously reduced density. The metal is said by the uninformed to have been "changed to plumbago" (Calvert).

4. Corrosion is rapidly effected with cast metal irregularly and quickly cooled in the mould, less rapidly where slowly and regularly cooled (Mallet).

5. The rate of corrosion is ordinarily constant over long periods of time; but the removal of dust retards oxidation, as it destroys the voltaic couple composed of metal and of oxide.

6. Hard iron, rich in combined carbon, rusts slowly. The presence of graphite or of a different quality of iron in metallic contact with it increases the rate of oxidation,—presumably by forming local voltaic samples. Hard steel rusts less rapidly than soft.

7. Foul sea-water, as the bilge-water of a ship, corrodes iron and steel rapidly.

8. The rate of corrosion is too variable to be stated in exact terms. The hulls of iron ships have been found to average a rate of not far from $\frac{1}{16}$ inch in twenty-five years when carefully painted. Iron roofs exposed to smoke and gases of locomotives are sometimes ruined in three or four years.

9. The observations of Thwaite are as follows: The time of endurance in years may be expected to average about

$$T = W \times CL;$$

where W is the weight of metal in pounds per foot length of the member; L is its length of perimeter inside and out if it is hollow; and C is a constant which has the following values and the magnitude of which measures the relative loss by corrosion:

	Water.				Impure Air.
	Sea.		River.		
	Foul.	Clear.	Foul.	Clear or in Air.	
Cast iron	0.0656	0.0636	0.0381	0.0113	0.0476
Wrought iron	.1956	.1255	.1440	.0123	.1254
Steel	.1944	.0970	.1133	.0125	.1252
Cast iron, no skin	.23	.0880	.0728	.0109	.0854
Galvanized	.09	.0359	.0371	.0048	.0199

Average for sea-water, cast iron, in contact with brass, copper, or gun-bronzes, 0.19 to 0.35; wrought iron, in contact with the same, 0.3 to 0.45. This is for unpainted metal, of course.

For painted iron or steel it is safe to multiply the endurance, as above, by two or more.

The above are general statements, and there is no clue to analysis or quality of the metals themselves, and the above figures should be considered in this light.

Mr. Thos. Andrews, F.R.S., writing on the effect of stress on corrosion of metals,* gives a table of the electromotive force obtained between strained and unstrained portions of the same metal, which varied from 0.002 to 0.019 volt. In all these tests the strained metal was the electropositive.

Corrosion is always accompanied by electrical energy of greater or less intensity or electromotive force, according to the substance consumed.

Mr. Carl Hambuchen, B.Sc.,† says concerning corrosion: "In many if not all cases the character and rapidity of ordinary corrosion of iron and steel depend upon their physical and chemical properties, and the galvanic action due to differences of potential between different parts of the metal."

In addition to boiler materials being under strain, they are subject to very high and variable temperatures, which also contribute to assist the work of corrosion.

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* Proc. Inst. C. E., 1893-94. † Bul. Univ. of Wis., Vol. 2, No. 8.

CHAPTER IV.

FEED-WATER PIPES.—BLOW-OFF PIPES.—TUBES.

We all know that the feed-water inlet in a steam-boiler is one of the parts of a setting that are subject to hard usage, and in the furnace this piping is subject to all the ills of the boiler itself. It frequently happens that in neglected plants the pipe is almost closed with mud and scale.

Fig. 22*a* shows a ruptured blow-off pipe, the rupture caused by a deposit of scale and sediment lodging in the pipe, and indicated

(Fidelity & Casualty Co.)

Fig. 22*a*.—Ruptured Blow-off Pipe.

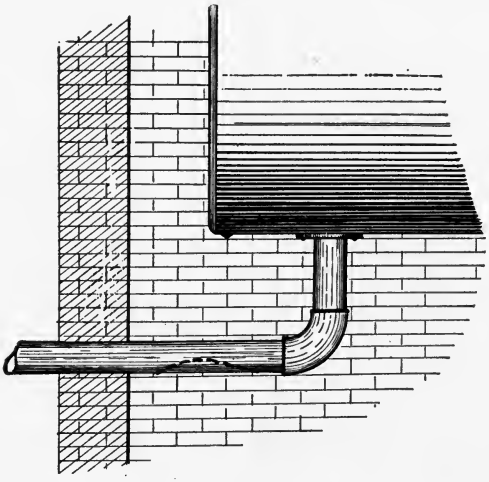
by Fig. 23. When the pipe broke, the steam dug a hole in the ground, and also opened the furnace-doors and cleaned the wood fire off the grates. The steam-gauge indicated 100 pounds pressure.

After inspecting a horizontal tubular boiler in South Carolina, C. C. Davis, of the Fidelity and Casualty Company, reported a little information worthy of preservation.

"There is a small bag on the bottom of the shell near the rear head, due to the blow-off pipes being tapped into the rear head about 3 inches above the bottom of the shell. The metal in the bag

is in good condition and is not down over $\frac{5}{16}$ of an inch, and we would recommend that the blow-off pipe be tapped into this bag. There is also a slight pitting, mostly on the tube surface, and we would recommend the use of carbonate of soda for the purpose of preventing the pitting from extending. The soda should be introduced continuously through the feed-water, in a quantity that will best be determined by experiment.

"Care should be taken to open the boiler shortly after the soda has been introduced, and to remove whatever scale has accumulated on the sheets, as otherwise serious trouble is liable to be caused



(Fidelity & Casualty Co.)
FIG. 23 —Side Elevation of Blow-off Connection.

through the overheating of the metal. Care should also be taken to open the surface and bottom blow-off pipes at frequent intervals, in order to prevent the density of the solution from becoming too great, as otherwise priming is liable to ensue."

Condenser-tubes.—W. A. Stewart, in a paper before the Institute of Naval Engineers, 1903, said that serious corrosion on condenser-tubes on board ship is often laid to the charge of faulty wiring.

One Channel steamer that had such trouble was wired on the single-wire system, and though having seen but one year of service, some of the condenser-tubes needed renewal.

At the same time a twenty-year-old paddle-wheel steamer

showed the same trouble; it was not wired at all for electricity, but both had been moored together near the outlet of a sewer from a galvanizing works, where many acids were discharged, and it was this foul acid water that caused the trouble.

The elements used in alloys may be electrochemically arranged, so that each element will be positive to any above it and negative to any below it. The oxides of elements are electropositive to their own elements.

The nearer together the metals are in the list the less will be the difference of potential:

Copper,
Tin,
Lead,
Nickel,
Zinc.

A flow of electricity is always set up where there is a difference of potential. Electrolysis or electrochemical action occurs at the expense or using up of the electropositive element or oxide, and can be accelerated, or vice versa, by the contact liquid.

As to oxidation, pure copper cannot be cast without the oxidation of the metal, which shows itself after the metal is drawn to a tube or other form, and the places of oxidation are the beginning of pitting and finally holes in the tube.

Brass tubes always contain some zinc, which is positive to the copper and corrodes very easily; and the zinc being thus entirely liberated, the strength of the tube is also reduced materially.

Nickel is very inert, that is, slow to act or be acted upon.

In the French battleship Brennus copper tubes corroded in a very short time and much more rapidly than the brass tubes in use.

The deterioration from corrosion of the parts of compound boilers, such as mud-drums, heaters, water-bottoms, water-legs, and the like, which are located below the active generating surfaces of a boiler is a notable experience in boiler practice.

This corrosion is most frequently caused by the condensation of acid vapors from the furnace-gases upon the cooler surfaces, or by the salts of acids deposited with soot and ashes; the corrosion of steel chimneys where the ashes lodge on the joints of the sheets

and is washed through the joint by moisture is another example of corrosion from this cause and which occurs in steam-plants.

It makes no difference whether the boiler is in steady or intermittent use or not, nor how good the metal is; in fact, the common impurities of iron are least soluble in acids and resist for a long period any tendency to corrosion.

Brass pipe should never be used for internal feed-pipes or for blow-off connections; it may, however, be used for external feed-pipes which are not exposed to very high temperatures, and where

FIG. 24.—Effect of Electrolysis upon Brass Tubes.

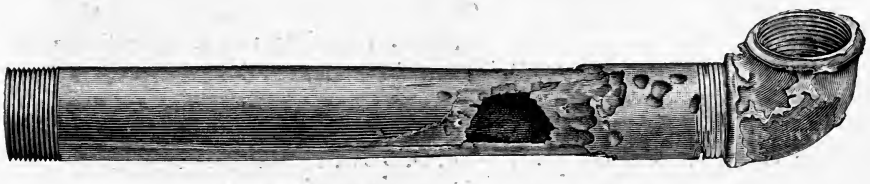
the feed-water is of such a character as to be liable to produce pitting.

Heavy iron pipe is the best for internal use, that is, inside of the boiler, and is likewise much cheaper than copper or brass pipe. An inch and a quarter inside diameter $\frac{1}{8}$ inch thick iron pipe used as a feed-pipe entered a boiler from the top through a bushing, and the brass pipe (Fig. 25) was screwed into this bushing inside the boiler in a vertical position, with its lower end (elbow end) just below the water-line and just above the top row of tubes. A horizontal iron pipe from the elbow took the feed-water toward the rear end of the boiler. While the brass pipe was much corroded the iron pipe was not affected.

"The boiler in question was situated in a shoe-shop in Massachusetts, in a part of the State where the water is more or less

hard, soda-ash and kerosene being used to prevent the accumulation of scale. The boiler was three years old, and the brass pipe had been in use for the same length of time.

"The feed-water was drawn from the town supply and was heated in a coil heater with exhaust-steam. It was metered, and, naturally enough, an effort was made to economize in the consumption of it, so far as possible. The drips from the shop were all returned to the feed-tank, together with the condensed water from the heater. As a result a considerable quantity of greasy matter was introduced into the boiler along with the feed, and some trouble was experienced through the starting of the girth joint over the fire. The drip from the heater was then disconnected



(From "The Locomotive," Hartford S. B. I. & I. Co.)

FIG. 25.—Corroded Brass Pipe from the Interior of a Boiler.

from the feed-tank and allowed to run to waste. This prevented the introduction of grease, so that the boiler became much cleaner and no further trouble was had with the joints. The change was made last January, and the boiler was not inspected internally at that time, so far as we are aware.

"The large hole in the corroded brass pipe came just at the usual water-line, and the natural inference would be that the destruction was due to the corrosive action of the floating grease, which would be gradually decomposed by the heat with a corresponding liberation of the fatty acids it contained. There are several objections to this hypothesis, however. In the first place, the pipe was in good condition when the last internal inspection was made, a year ago, although it had been exposed to the grease two years. Twenty-four months of exposure had not noticeably affected it, and yet the seven months that elapsed between the last inspection and the disconnection of the heater had entirely destroyed it (assuming the grease theory to be correct). Again, there is another boiler in the same room eight years old which also has a brass pipe

in it arranged in the same way. There is no observable difference in the conditions under which the two boilers are run, nor in the manner of feeding them, and yet the brass pipe in the second boiler, which is five years older, is far less affected, although it does show signs of the same action. The shell-plates along the water-line are perfectly sound in both boilers, with no indications of pitting or corrosion.

"It has also been suggested that the action was of electrical origin, and that it was due either to the dynamo in the next room, used for lighting the shop, or to the simpler fact that the feed-pipe was constructed of two metals, brass and iron, which would naturally produce a galvanic couple when submerged in the water of the boiler.* In support of the first view, it is alleged that the corrosion dates practically from the time the electric lights are introduced; and yet it is hard to understand how an electric action from such a cause could take place within the closed conductor formed by the boiler-shell. If the corrosion were of electrical origin, it seems more likely that the source of the electricity was within the boiler; but in that case we fail to understand why it was not observed before.

"As may be inferred from what has been said, we are not prepared to offer any conclusive theory with regard to this particular case of corrosion. The brass pipe here illustrated has been replaced by an iron one, while the corresponding brass pipe in the neighboring boiler has not been disturbed. The conditions under which the two boilers are run have not been otherwise changed, and it will doubtless be instructive to observe the subsequent course of events.

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* Faraday made elaborate investigations of the electrical condition of the interior of a conductor which was charged on the outside with electricity. In the course of one of his experiments he built a large hollow cube, 12 feet square, and covered it all over on the outside with copper wire and tin-foil. He took delicate electroscopes into the cube, but could not detect any electricity at all, even when the outside was strongly charged. "I went into the cube and lived in it," he says, "and using lighted candles, electrometers, and all other tests of electrical states, I could not find the least influence upon them or indication of anything particular given by them, though all the time the outside of the cube was powerfully charged, and large sparks and brushes were darting off from every part of its outer surface." (*Experimental Researches in Electricity*, by Michael Faraday, Vol. I, p. 366.)

"In conclusion, we may say, that in our judgment, brass should never be used either for internal feed-pipes or for blow-offs. It does very well for external feed-pipes, which are not exposed to heat, but in other places it cannot be recommended. Iron is much better."

Corrosion.—Mr. Victor Beutner,* in a paper on "The Manufacture of Welded Pipe," says: "Generally speaking, steel presents less difficulties in manufacturing than wrought iron, being much 'cleaner' to handle and furnishing a more uniform and reliable product.

"The only exception is the well-known power of resistance of pure wrought iron to the influence of rain or other atmospheric moisture, and to the corrosion by the soil, if exposed to either without protection. In such case the wrought-iron pipe will outlast the steel pipe nearly three times."

This is the testimony of an engineer of long experience in pipe manufacture.

Again, Mr. Alex. B. Moncrieff, South Australia, with experience in the use of the very best wrought-iron casing in deep-well bores in the above country, says that in wells from which the water flows at considerable velocity, and at temperatures as high as 204°, piping sometimes rusts through. The water is mineralized, probably with sodium chloride (common salt), by which either steel or iron would be corroded.

Durability of Wrought-iron Pipe.—A section of water-pipe 30 feet long taken up in 1899 at Rochester, N. Y., was 25 years old. It was a thin riveted wrought-iron pipe $\frac{1}{8}$ of an inch thick, laid in 1874 by Thos. Leighton as a portion of a 24-in.-diameter supply-pipe from Carrol to Fitzhugh Race to the Holly Pumping Station. The pipe was practically as good as when it was laid 25 years ago, and with probably an equally long life ahead of it. The pipe was made originally for another use.

From a discussion in *Engineering News* † on quality and durability of steel and wrought-iron pipe it is brought out that steel pipe corrodes much quicker than wrought iron; that steel tubes have been quite universally discarded for locomotive boilers.

Old-fashioned corrugated iron lasted twenty years on buildings

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* Eng. News, Vol. 51, p. 425. † Vol. 50, pp. 286, 296, and 502.

where the new, so called (probably steel), lasted three years. A general manager of one of the large steel-mills freely admitted that steel was more easily corroded than wrought iron.

After telling how the two products are manufactured, Mr. Jas. P. Roe, M.E. and superintendent of iron-works of the Glasgow Iron Company, Pottstown, Pa., says: "It is probable that the high phosphorus that iron will safely carry, compared to steel, tends to help in its resistance to oxidation, as steel high in metalloids appears to resist oxidation better than steel low in metalloids. Steel finishes smooth, while iron finishes rough, and is better prepared to receive and hold a protective coating, whatever it may be."

Another thinks steel made by the basic process changes its character and improves with age; in other words, it will not corrode after reaching a certain age.

A steel company having corrugated covering put on a building would not allow steel, but insisted on wrought iron.

Mr. Chas. H. Manning, superintendent of the Amoskeag Company, Manchester, N. H., says in part: "There is no denying the fact that steel boiler-tubes will pit much sooner than iron tubes, or, I should say, will pit where iron tubes will not, and I never use steel tubes.

"I have recently retubed a boiler, built in 1898, with as good charcoal-iron tubes as I ever used, and yet they were ruined by pitting.

"This boiler had been fed on city water where there was an alum coagulant used in the filter. However, tubes of the same make and the same lot used in other boilers built at the same time are perfectly good."

Mr. Manning prefers steel to iron except in boiler-tubes and small piping, his objection being that steel pipe is harder to make up well and is ruinous to dies for large sizes of pipe.

In two plants known to the author, in the same city, one uses river-water and has no trouble with corrosion, while the other uses city water in which alum coagulant was used in the filtration process, and the feed-piping of this plant has been entirely corroded through in less than five years.

A 3-inch extra-strong wrought-iron pipe, replacing a pipe lasting fifteen years, using same water-supply failed by corrosion.

Investigation as to its cause showed the water to be contaminated with sewage. The corrosion along the top of the pipe and

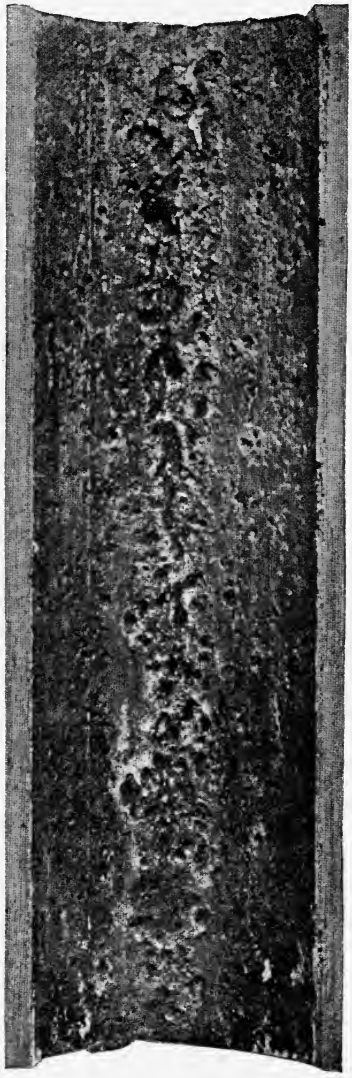


FIG. 25*a*.—Corroded Wrought-iron Pipe.

the decomposition of the sewage to H_2S and CO_2 mixed with air in a trapped portion of the line did the work quickly.

The corrosion was not uniform, as has been thought by some to be the case with wrought iron.

Mr. Frank N. Speller, in closing the article in the *Engineering Record,* Vol. 51, p. 654, from which the above is taken, says: "It would therefore seem that environment is the determining factor in corrosion, compared with which any difference there may be between the relative tendencies of wrought iron and soft steel to rust is usually trivial."

Sweet's Mud-catcher. — While feed-water heaters catch some of the impurities before the water reaches the boiler at a temperture below 212° F. in closed heaters, in John E. Sweet's mud-catcher the work is done much better, partly for the reason that it is located inside the boiler and is heated to a very high temperature.

The feed-water enters the boiler at the top, is passed through a spray-plate, and enters the tank *A*, passes down through the tube *B*, entering the mud-catcher *C*, out of which it cannot escape except through a narrow slit in its upper side.

Notwithstanding the Syracuse, N. Y., water is thought to be the best in the State, the mud-catcher soon fills up, making it both advisable and necessary to clean it often rather than have it overflow and the "stuff" accumulate on the bottom of the boiler.

The blow-off connection is placed in the front of the boiler, and, as may readily be seen from the figure, is entirely protected by brickwork.

In a letter to the author from John E. Sweet, he says: "This Yankee nation, of which we boast so much, is the stupidest in some things of any in the world. The papers are all the time pointing out where other nations are copying our things right and left, where we will neither copy the best of what other nations do, and we won't copy ourselves.

"For ten or a dozen years I have been showing our mud-catcher (one of the most simple and sensible things I ever devised) to everybody, but nobody adopts it."

A somewhat similar device has been in use on locomotives of the New York, Chicago, and St. Louis Railroad, and has been illustrated in the Report of the Master Mechanics' Association, as shown by Fig. 27.

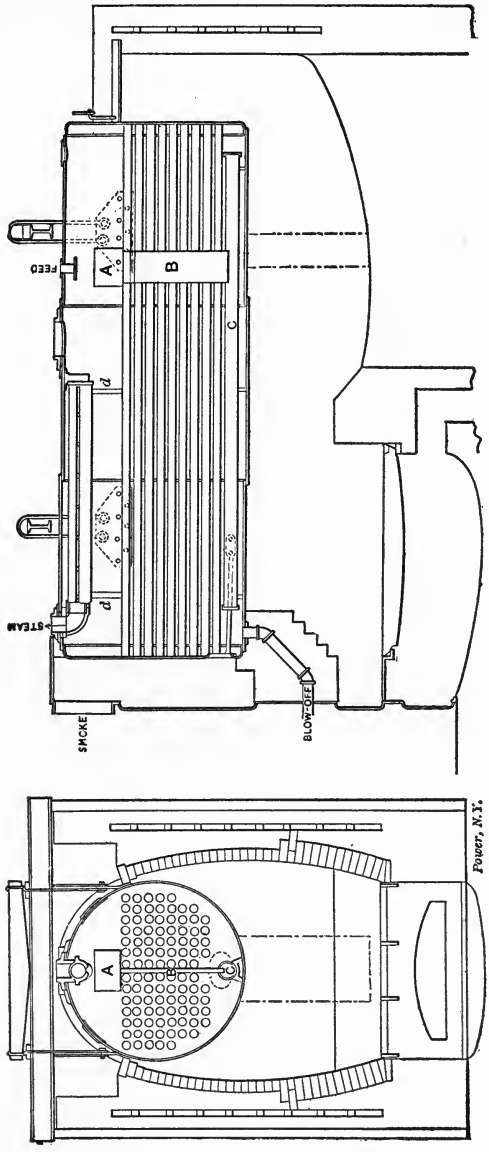
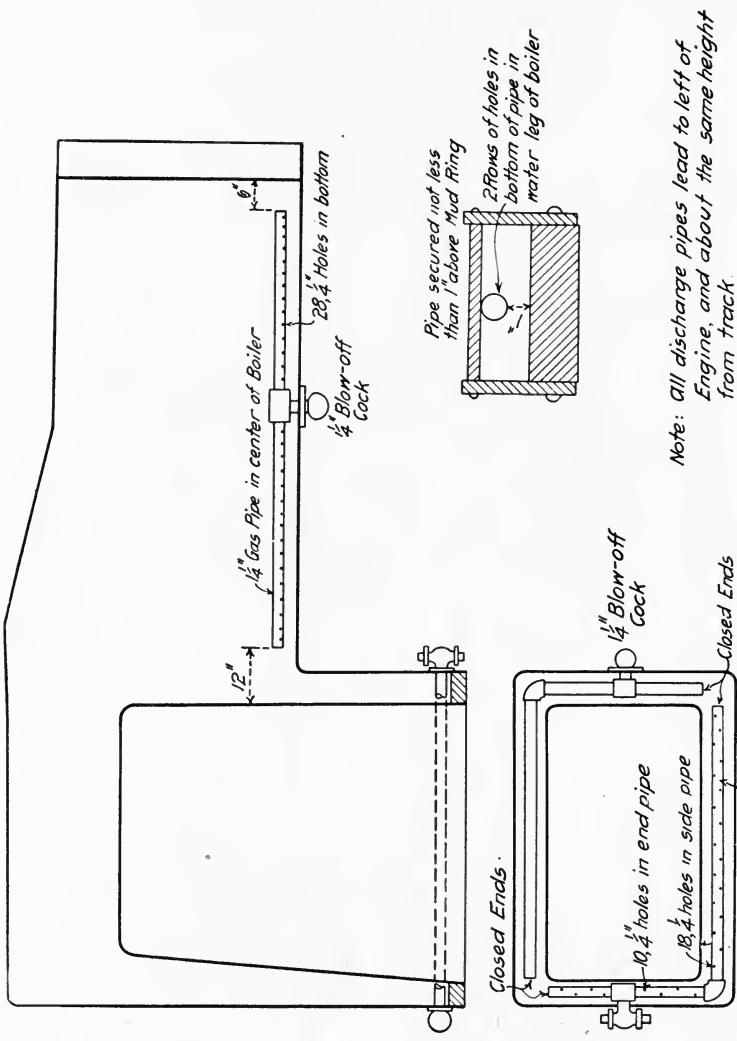


FIG. 26.—Prof. John E. Sweet's Boiler-setting.

In this case, however, the pipe along the boiler bottom is much smaller, and serves as a mud "scourer," not as a "catcher."


6"
28, ¼" Holes in bottom
¼" Blow-off Cock
¼" Gas Pipe in center of Boiler
12"
Pipe secured not less than 1" above Mud Ring
2 Rows of holes in bottom of pipe in water leg of boiler
Note: All discharge pipes lead to left of Engine, and about the same height from track.
¼" Blow-off Cock
Closed Ends
Closed Ends
10, ¼" holes in end pipe
18, ¼ holes in side pipe
1" Gas Pipe

(From "Railroad Gazette.")

FIG. 27.—Mud-cleaner, New York, Chicago, and St. Louis Railroad.

This device insures the sediment being blown out from the entire lengths of places of settling, instead of only at blow-off cock outlet, as is so often the case in the ordinary boiler-setting.

Cooling of Boilers.—M. E. Wells says: "A boiler with 200 pounds of steam should be given at least 1½ hours to cool, to no steam pressure, and the boiler should be well filled with water all the time. Water should stay well above the crown-sheet until the water in the boiler is cooled to 90° in summer and to 70° in winter. The reason for this is that wash- and filling-water will average from 20° to 30° F. colder in winter than in summer. This applies where water is used from streams or tanks. Where it is pumped from deep wells, there will not be this difference. It is a well-known fact that boilers leak more in winter than in summer. Many consider a boiler cool when the steam is gone, and draw the water out. It is just about half cool, for it is 176° from 388° (200 pounds steam) to 212° (no steam), and it is 152° from 212° to 60°, the temperature of average wash-water.

Blowing-off.—Mr. N. O. Goldsmith * very aptly says: "To lengthen the intervals between washing out, made necessary by concentration to a dangerous degree, it is found that regular blowing down of water from one to two gauges, depending upon the type of boiler, and pumping up fresh water is decidedly beneficial. There are twenty-two Cahall vertical boilers, 250 horse-power each, at the blast-furnace plant; in normal working condition each of these holds 292 cubic feet, equal to 2200 U. S. gallons. When 6 inches are blown down about 100 gallons of water are discharged; if this is done once every twelve hours, an amount equal to the entire capacity of the boiler is blown away in eleven days. The objection to blowing out hot water and pumping in cooler water is recognized as not being an economical practice, but it is one of the penalties steam-users must pay when they are compelled to use water containing comparatively small amounts of soluble impurities and want to keep their boilers free from scale. Therefore in order to get the best condition, it is necessary to make chemical analysis not only of the raw water and the treated water but also of the concentrated water from the blow-off cock. This should be started when clean boilers are put in service and samples should be taken at regular intervals and the concentration watched. By this means it can be determined how long it is safe to run without washing; this interval will vary with the

* Trans. A. S. M. E., Vol. XXI, p. 882.

condition of the raw water at different locations, as upon the raw water depends the character of the softened water.

"If the length of time between boiler-washings can be increased three or four times over what was necessary before softened water was used and regular blowing down put in practice, and if it is found unnecessary to use scrapers or tube-cleaning machines at all, because no scale accumulates or builds up, if open-exhaust steam-heaters can be run from six months to one year without cleaning, if no live-steam purifiers are required and no boiler compound used, then by the use of softened water the percentage of idle capital is decreased. The fuel economy is increased, first, because a clean heater gives hotter feed-water; second, the fuel used to heat up a cold boiler is more than that used to keep steam in a hot one; third, a clean boiler will evaporate more water than a dirty one."

In marine work the old rule was to begin "blowing-off" as soon as the proportion of saline ingredients had become about twice the normal in sea-water, and this was kept up steadily throughout the voyage.

The idea as to what would have happened if there had not been the blowing-off must have been something wonderful, for the amount of scale which was actually produced under this regimen was enormous.

It has been shown that sulphate of lime is deposited not so much on account of increased density as by elevation of temperature, thus forming an exception to the usual rule with salts which are more readily soluble in hot than in cold water. In fact, when the steam pressure was in excess of 60 pounds every bit of sulphate of lime would be deposited, even before any of the water was evaporated. The method followed therefore increased the deposit of scale, involving as it did an increased amount of sea-water.

CHAPTER V.

PRIMING AND FOAMING.

Priming.—A boiler is said to prime when water is carried as steam-bubbles, with the steam up, through the water to its surface, and may be considered as affecting the entire depth of the water in a boiler.

Foaming is the result of suspended impurities in the water, which rise to its surface in a more or less dirty condition and forms a scum. Pure water cannot produce foam; steam from a boiler which foams is dryer than that from a boiler which primes.

Surface blowing-off is a remedy for foaming; foaming is a surface condition. A boiler supplying dry steam, when not overworked, may prime heavily when it is hard pressed.

William A. Fairburn, in a paper on "The Water-tube Boiler in the American Mercantile Marine," read before the Soc. Nav. Archs. and Marine Engrs., 1902, says: "Water which causes priming produces foam in the boiler, consisting of a mass of bubbles, so durable that they remain a considerable time without breaking, and by them the steam-space of a boiler may be entirely filled. When this takes place, instead of steam leaving the boiler, the discharge is composed of foam, which becomes broken up in its journey through the steam-pipe and is carried into the engine cylinders as water. Pure water is incapable of forming bubbles. Sometimes sea-water will work in a satisfactory manner, but when mixed with fresh water, priming takes place. There are so-called pure fresh waters that cannot be mixed without priming, and Mr. Fairburn has had such an experience with water from springs, surface reservoirs, and a sunken well, all taken within a radius of 300 feet. But all these facts apply to Scotch boilers as well as water-tube boilers, the only advantage in favor of the fire-tube

boiler being less work involved in 'brining' or 'blowing-off.' Some of the Thorneycroft-built torpedo-boats, fitted with small tube boilers with accelerated circulation, we are told, have steamed for weeks with nothing but salt water in the boilers and no trouble has been experienced.

In the early days of railroading on the B. & O. a locomotive with a round fire-box boiler, something like the style of the present Fitzgibbons boiler, always primed when pulling a train up a certain grade. If feed-water was pumped into the boiler at this time, priming would cease at once, the cause of the trouble being the intense heat, which impinged upon the water-leg of the fire-box with restricted water space, which was partially empty.

The vertical staggering of tubes in fire-tube boilers used to be considered the best way to distribute the flues. Under the low-steam pressures then in vogue there was no trouble from priming with boilers so built, which, however, is the tendency when the high pressures now in vogue are used, notwithstanding the fact that the tendency of a boiler to prime decreases as the pressure of the steam increases and increases as the water surface diminishes.

Mineral oil is sometimes injected into boilers to prevent priming.

To cure priming on the U. S. steamship Galena, bolts were substituted for some of the tubes coming under the smoke-stack.

If foaming or priming is especially violent, the draft should be shut off at once and the fires covered up until the cause can be removed.

The writer recently tested three horizontal return tubular boilers, one of which had been cleaned a few days before the test, the other two being dirty. With a total heating-surface of 5880 square feet, during a ten-hour test these boilers developed 514 horse-power. At two different periods during the test, when an extra supply of steam was demanded from the boilers, the two dirty boilers primed badly, and the extra load had to be carried by other boilers in the steam-plant, the one clean horizontal boiler giving no trouble. Since the test was made the two boilers were opened and found to contain considerable scale, varying from $\frac{1}{16}$ to $\frac{3}{16}$ inch in thickness, of a very dark color, the surface being dark red only and the scale very rotten to the touch; considerable fine dirt of the same general character was also found. These

troubles are caused by contracted water-space and steam-liberating surface, by contracted steam-space, by boilers poorly designed, and by trying to get a much higher boiler horse-power than the boiler was designed to give.

Foaming.—The alkali solids or those which cause foaming include:

Salts of sodium;

Salts of potassium;

Sodium chloride.

One water in the West which contained 1.16 grains per gallon of sodium sulphate before softening, had 20 grains of the same after treatment, and in the same part of the country experiment has shown that water containing 175 grains per gallon of alkali (sulphate and carbonate of soda) has caused locomotive boilers to foam badly.

It may have been noticed that sodium sulphate is the most prominent substance in softened water in many cases. It is an absolutely neutral salt, and sodium and sulphuric acid being about the strongest alkali and acid, it is not possible to find a stronger one of either class to break up the compound.

The amount of sodium sulphate usually present in softened water does no harm. If water is specially high in this salt, blowing-off must be practiced to prevent too great concentration or foaming will be the outcome.

There are no two types of boiler exactly alike in their working; one boiler is better suited to its work than another type would be to take its place.

One of the prominent manufacturers of softeners conducted some experiments to see what amount of sodium sulphate several types of boilers would carry and not cause foaming; he found these figures to be approximately correct:

A. Old-type two-flue boiler, 1000 grains of sodium sulphate (Na_2SO_4) to the gallon when the boiler was working at its maximum capacity. Steam pressure, 50 pounds.

B. Ordinary horizontal return tubular boiler, 500 to 600 grains; same conditions. Steam pressure, 100 pounds.

C. Modern water-tube boiler, such as the Babcock & Wilcox or Heine, 300 to 400 grains; same conditions. Steam pressure, 125 pounds.

D. Stirling boiler, 250 to 300 grains; same conditions. Steam pressure, 125 pounds.

E. Locomotive boiler, 150 to 200 grains; same conditions. Steam pressure, 200 pounds.

It was found that the steam pressure carried had very little or nothing to do with the results tested for. Allegheny River water was used, and had passed through a filter before going to the boilers, so probably did not contain much organic matter.

Carney * says foaming is caused by interference with the free escape of steam from the water in the boiler, and manifests itself by the rising and frequent appearance of boiling of the water in the water-glass and by water in the steam.

He gives as causes: 1, sodium salts; 2, mud or suspended matter; 3, organic matter. Mud and organic matter can be removed by filtration, but there is no practical way of getting rid of sodium salts. The sodium salts in solution increase the surface-tension and thereby prevent the free escape of steam from the water.

Bubbles formed in rapid succession constitute a froth which fills the steam-space of the boiler and passes over with the steam.

Locomotive boilers foam with 75 to 200 grains of alkali per gallon, while stationary boilers have been run successfully without foaming with 650 grains of sodium salts and more per gallon. A case is given of a stationary boiler with 8.7 times the steam-liberating surface that we find in a locomotive boiler, which explains in part why the locomotive boiler foams the easier.

C. Herschel Koyl, in the *Railroad Gazette* of October 12, 1900, says: "I have reasons for the belief that, under ordinary conditions of service, boiler-foaming takes place only in the presence of particles of matter suspended in the water in the boiler. This belief is at variance with the usual opinions on the subject, and I therefore present some of my observations and the conclusions I have drawn therefrom.

"Not all the causes of foaming are known with certainty, I believe, to any one. The general belief † appears to be that foam-

* A. Inst. Min. Engrs., 1897.

† American Railway Master Mechanics' Association: Report of Committee on the Best Method of Preventing Trouble in Boilers from Water Impurities, 1899.

ing is produced by the presence of the salts of sodium—alkali salts—commonly called alkaline salts, though some of them are not alkaline at all, sodium chloride, for instance, being common salt and having no alkaline reaction, sodium sulphate being just as neutral as sodium chloride. But I have not been able to find evidence of water caused to foam by the alkali salts except in the presence of matter in suspension.

"In the laboratory I have many times fed into boiling distilled water quantities of chemically pure sodium carbonate, up to several hundred grains per gallon, without producing any foaming effect. But if there is fed into the boiling distilled water a fine insoluble powder, such as calcium carbonate or magnesia alba, the water will soon be foaming as vigorously as any one could wish.

"If hard water is used in a boiler of any kind until a scale has been formed and the boiler then is fed with rain-water or any other soft water, a disintegrating action upon the scale begins immediately, the water is filled with floating particles of loosened scale, and a violent foaming ensues.

"It is frequently the case in railroad service that a locomotive is supplied from a tank containing hard water, which, of course, begins to form scale in the boiler, and that later the locomotive is supplied from another tank containing alkaline water. In this case the action of the alkali is exactly the same as the action of the rain-water, or of soda-ash when used as a boiler compound, and its effect is not only to precipitate scale matter from the hard water, but also to disintegrate the scale attached to the boiler and, from these two sources, to fill the water with floating particles, which soon start the boiler foaming.

"It has been the common practice to attribute the foaming of the boiler to the alkaline water, because it was fed in just before the foaming began, while according to my opinion it was only the loosened scale matter which produced the foaming, and there would have been no foaming had there been no scale. It is perfectly natural, in the absence of other information, to ascribe the foaming of a boiler to the last water which was put in; but in the same manner it might be asserted that two taps of the bell move a street-car, because the street-car moves immediately after the two taps are heard.

"Three physical conditions are recognized in boiling liquids

in the laboratory, and doubtless may exist in boilers of any size and pressure: (1) 'Bumping,' when the steam rises in great bubbles and tears such holes through the liquid that vigorous thumping upon the bottom of the vessel is produced by the liquid falling back to its place; (2) 'Quiet boiling,' when the steam appears to enter the water freely and to rise through it without difficulty; (3) 'Foaming,' when the steam and the liquid appear to be so intimately mixed that they cannot easily be separated, and the liquid is carried up and out with the bubbles of steam.

"In making ammonia determinations by the Kjeldahl method there is frequently much difficulty in preventing, on the one hand, bumping, and, on the other hand, foaming of the alkaline liquid during distillation. If a caustic-soda solution, strong and clear, is used to liberate the ammonia there is great bumping, frequently of sufficient violence to shatter the flask. If a caustic-soda solution, strong and turbid (from various suspended impurities present in the commercial article), is used there is furious foaming. But if a caustic-soda solution, strong and clear, is used and zinc dust is added to the proper amount (very little suffices) a point is reached at which the bumping ceases and foaming does not commence; while if more zinc dust is added foaming follows. This illustration appears to me to be free from complications and to leave open no other conclusion than that bumping is obviated, and the liquid caused to boil quietly, by the introduction of a small amount of insoluble powder; and that, given a quiet-boiling liquid, foaming is produced by the addition of a little more insoluble powder.

"Fortunately there are analogies for illustration which may explain why a few particles of foreign matter may prevent boiling water from bumping and more particles may cause it to foam. It is well known that perfectly clean water in a perfectly clean vessel may be cooled below 32° F. (0° C.) without freezing, or that it may be heated above 212° F. (100° C.) without boiling; but that dropping into it a small piece of solid matter of any kind will cause it in the one case to begin to solidify along the course of the particle and in the other case to burst into steam along the course of the particle. These are the phenomena of supercooling and superheating, and are generally ascribed to the viscosity or cohesion or internal friction of the water which prevents, on the one hand,

freezing, or, on the other hand, the formation of steam bubbles, until, in the one case, the crystallizing force is in excess, or, in the other case, the internal vapor-tension exceeds considerably the external pressure or vapor-tension.

"If now perfectly clean water in a perfectly clean boiler tends to remain at rest and therefore to become superheated at the heating-surfaces, and to liberate its steam only at intervals and then to 'bump,' the addition of some foreign matter, such as is in all ordinary water, will release the steam more frequently, and may be made to do it at such intervals as to result in quiet boiling; while if these particles are increased in number, the liberation of steam throughout the water in the vicinity of each particle may produce such an almost infinite number of bubbles that the boiling water becomes a seething mass so filled with bubbles as to occupy the whole space of the boiler and to make it impossible for the bubbles all to break at the surface without throwing up quantities of water to go over mechanically with the steam. This is foaming.

"In boilers working at a high temperature there is seldom noticeable bumping, because the water is separated from the heating surface by a thin layer of steam, and this prevents the superheating of the water which gives rise to the sudden bursts of steam which produce bumping. If, however, the boiler is covered with scale which separates the water from the hot iron, and a piece of this scale is loosened in any way so that some of the water may strike the iron which is at a much higher temperature than the water, a sudden burst of steam takes place sometimes sufficient to rupture the boiler. If a stream of cold water condenses the film of steam and so reaches a hot boiler-sheet, the same sudden burst of steam may take place with the same result of bursting the boiler.

"The point to be remembered, is that this bumping in any of its forms is due to the superheating of the water; and to the sudden release of large quantities of steam at the heating-surface. When the water contains a small number of particles in suspension, each of these particles serving to release the steam and therefore the superheating in its immediate vicinity (as is easily seen by observing the phenomenon in glass vessels) the result is quiet boiling. When the water contains a very large number of sus-

pended particles, each serving to release the steam in its immediate vicinity, steam bubbles are formed not merely at the heating surfaces and not merely at a few other places but in every part of the water, with the result of increasing the space occupied by the water to such an extent that the water may be forced out of the steam-pipes.

"Of course a sudden reduction of pressure outside the boiler might carry over water in any quantity; water saturated with air or gas would boil with great disturbance, and then a lot of soap put into a boiler would produce very sticky wet steam, but by the limitation made in the first paragraph—'under ordinary conditions of service'—I have endeavored to eliminate from the discussion such causes as are not likely to exist in ordinary boiler work, but to include others which do occur, such as heavy hill-climbing when for a time the engine is calling for enormous amounts of steam and the water in the boiler must be in ideal condition if such amounts of steam are to rise through it without taking it along.

"Of the ordinary cases of boiler foaming: (1) That produced by the use of boiler precipitants I explain as above, and hold that the foaming is produced by the suspended matter in the water and without regard to the amount of alkali salts in the water, except in so far as this may be a gauge of the amount of matter precipitated; (2) That produced by the use of alkaline feed-water I explain in the same way, with the exception noted in a later paragraph; (3) The foaming produced by water from some of the western rivers which contain mud and organic matter appears to me to be explicable on this theory and on no other, for many of these waters contain no alkali; (4) The foaming sometimes produced in a locomotive fed from a water-softening machine, may be due to either of three causes, (*a*) the boiler may have been coated with scale which the soft water disintegrates and loosens, (*b*) the water furnished by the machine may not have settled well, nor have been filtered, so that it contains matter n suspension when it enters the boiler, or (*c*) the machine may not have been capable of completing the softening of the water (there are such machines), but if the proper amount of chemicals has been supplied to the water, this softening action—this scale-matter precipitation—is completed within the boiler and of course produces foaming.

"It is probable that the presence of alkali salts does, by increasing the surface-tension of the water, increase the severity of the foaming which results from the cause above mentioned; but, so far as I know, the production of foaming by the use of, say, salt water—alkali water but not alkaline water—takes place only when the solution is so concentrated as to be filled with particles of solid salt; and the view of the case which holds that foaming is due to alkali alone could be established only by feeding perfectly clean alkali water into an absolutely clean boiler, which, it is needless to say, is difficult to find among boilers which have been in service.

"One apparent exception serves only to prove the rule. It is possible to have a clean alkali water, containing only sodium bicarbonate, foaming in a clean boiler through the combination of three causes: (1) the separation in innumerable bubbles of the large amount of loosely combined CO_2; (2) the concentration of the liquid so as to produce considerable surface-tension, and (3) the very rapid generation of steam in a boiler of inadequate steam space.

"Foaming occasions such loss of water and of heat, creates so much danger to the boiler from uncertainty as to the height of water, detracts so much from the power and efficiency of the engine, and has left unremunerative so many dollars sunk in wells the water of which cannot be used, that the benefits to be derived from a determination of the causes of foaming, and therefore of its remedy, are great, and I believe the railroad world would thank the *Railroad Gazette* to gather and present all the individual bits of knowledge (and perhaps of speculation) so that from them we may form a complete and consistent theory.

"In the issue of the *Railroad Gazette* of October 12, 1900, C. Herschel Koyl presented a paper bearing the title 'The Cause of Foaming in Locomotive Boilers.'

"At that time I had had no opportunity to make tests on a locomotive in service, and my statement was based upon theoretical considerations, laboratory tests, and observations on stationary boilers.

"During the months of May and June, 1901, however, through the determination of the management of the Rio Grande Western Railroad to learn the possibilities of purification in the matter

of the extremely bad water of the Colorado desert, I had abundant opportunity to test and demonstrate the correctness of my theory.

"The distance across the Colorado desert by the line of the R. G. W. R. R. from Helper to Grand Junction is approximately 175 miles. At each of the terminal points, Helper and Grand Junction (Ruby), there is one of my water-softening-and-clarifying machines to put into good boiler condition the hard and muddy waters which supply the railroad at these places. At intervals across the division there are some eight or nine other points at which water may be taken.

"Previous to my visit the locomotives had taken water at any of the different stations as required, and it had been noticed that the boilers generally foamed after taking soft clear water from my machines. Arrangements were made to equip one test locomotive with two water-cars of sufficient capacity to carry the locomotive with a freight train across the division with softened water only.

"Before starting the boiler was thoroughly washed at Helper so that all mud and loose scale were taken out (though a nearly uniform coat of hard scale $\frac{1}{8}$ inch thick remained), then the boiler and the two water-cars were filled with the soft clear water from my machine, and the test began. The run to the other end of the division was made, for the first time in the history of the locomotive, without the faintest sign of foaming, though the train was heavy and there are numerous grades, and the engine was not spared. At the end of the run, after blowing out the water from the bottom of the boiler to free it from the loosened scale, another supply of softened water was taken on from my machine at Ruby, and the return run was made with equally satisfactory results.

"Following this the operation was repeated day after day, until it was demonstrated beyond question that the locomotive supplied exclusively with the soft clear water from my water-softening machines could be operated to the limit of her speed and power without foaming, so long as the old scale, which was slowly flaking off, was not allowed to accumulate in the bottom of the boiler. It was found that the first run of 350 miles brought down enough fine scale to make her foam, when, of course, she had to be washed out, but as the old scale in the boiler gradually grew less it came

down more slowly, and soon we were able to run 1400 miles between washings.

"Then one day, after the boiler had been thoroughly washed out, I dissolved in the tender- and car-waters almost pure sodium carbonate, to the amount of 300 grains per gallon of water, and started the run with an extra heavy train — indeed about the limit of the hauling capacity of the locomotive—and there was for several hours no more sign of foaming, up hill or down, than if the alkali had been left out. Before the end of the run, however, large quantities of old scale were loosened and considerable foaming followed. That night we washed out of the boiler more than twice as much loosened scale as usual, and the next day repeated the test with similar results, viz., no foaming due to alkali, but later, plenty of foaming due to loosened scale whipped fine.

"This was the only demonstration lacking to my paper of October 12, 1900, and I now consider the statement proved beyond question that, 'under ordinary conditions of service, boiler foaming takes place only in the presence of particles of matter suspended in the water in the boiler.' "

Foaming is the cause of much waste of fuel and water, and also puts a very uncertain danger element right before you, for the height of the water in the boiler is not known to any degree of certainty, and foaming must be kept out of a boiler or the danger of explosion will be present to a very uncertain degree.

CHAPTER VI.

OIL.

In studying the efficiencies of all types of steam-engines it is found that with a very few exceptions all of the steam that is exhausted from them contains oil that has served its useful purpose as a lubricator, and this oil passing to the boiler, if the steam is condensed and returned as feed-water, is capable of doing great harm in the boiler by causing burnt plates and aiding corrosion.

It looks as though the steam-turbine would prove the most economical steam-engine now in the market, and with its low rate of steam-consumption per horse-power-hour when it is operated, condensing, we should bear in mind that no oil gets in the steam passages. A surface-condenser can be used in connection with it and the exhaust steam be returned to the boiler as pure feed-water without the necessity of using and maintaining any oil separators.

The use of a steam-turbine would result in a boiler plant of minimum size, and a much greater life in the boilers themselves, which latter benefit can only be fully appreciated by those who have had the troubles from the oil required to lubricate "oil-fed" engines.

The cost of maintenance and interest would also be very much less, in fact the above remarks will apply in a measure to all steam-plants using but little oil, and be the more applicable as the quantity becomes less and less.

L. F. Lyne * in testing two different boilers of 100 H.P. each for the efficiency of scale prevention used kerosene oil in one and petroleum in the other. Some of the results follow.

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* Trans. A. S. M. E., Vol. X.

	Kerosene.	Crude Oil.
After using one gallon each week for one month.....	No dirt or scale	Considerable loose scale.
Four months afterward.	Clean	One bushel of hard scale. Grooving in top of water-gauge glass and corrosion.

Corrosive action with loose, hard scales appeared always when the crude petroleum was used and disappearing while kerosene was used. The tar and wax in crude petroleum combine with the sediment in steam-boilers and form a paste that successfully keeps the water from reaching the sheet and it burns out.

Avoid bringing a torch too near a boiler which has had kerosene used in it, as the gas from the oil is liable to explode if a light is brought near its vent outlet.

Prof. R. C. Carpenter * in 1889 used refined kerosene in boilers badly scaled. The custom at this plant had been to knock off the scale, which was $\frac{3}{8}$ inch thick, with a hammer and scaling-tools, at an annual cost of $18 to $25, and then two-thirds of the heating-surface, being inaccessible, was not cleaned.

For tubular boilers 4 feet in diameter by 12 feet long the best results were obtained by using 2 quarts or $\frac{1}{2}$ gallon of kerosene per boiler per week. The oil, which cost $2 per annum, loosened the scale.

The artesian well-water used in the boilers had this analysis:

$CaCO_3$.....	206 parts in 1,000,000
$MgCO_3$.....	78 " " "
Fe_2CO_3.....	22 " " "

and traces of sulphates and chlorides of potash and soda.

C. W. Nason,* with a boiler 5 ft. in diameter by 16 ft. long, used half of the above quantity of crude petroleum to remove scale $\frac{1}{2}$ to $\frac{3}{4}$ of an inch in thickness, which in a month's time it did thoroughly, all being loosened up and falling to the bottom of the shell in large flakes.

In cases where it is necessary to use water in which the total solid residue is large, a heavy petroleum oil free from tar or wax,

* Trans. A. S. M. E., Vol. XI, p. 937.

which is not acted upon by acids or alkalies, not having sufficient wax in it to cause saponification and which has a vaporizing-point at nearly 600° F., will give the best results in preventing boiler-scale.

The action of this oil is to form a thin greasy film over the boiler-linings, protecting them largely from the action of acids in the water, and so greasing the sediment which falls as to prevent the formation of scale and keeping the solid residue from the evaporation of the water in such a plastic, suspended condition that it can be easily ejected from the boiler by the usual method of blowing-off.

If the water is not blown off sufficiently often, this sediment forms a kind of "putty" that will necessitate the cleaning of the boilers.*

Deposits of grease on a boiler-shell, especially fatty substances readily decomposed by heating, seriously interfere with the transmission of heat. In Blechynden's and Durston's experiments it was found that the slightest trace of grease on a boiler-plate caused a decided fall in the rate of heat transmission.

The practice (1893) of W. A. Doble, of the Technical Society of the Pacific Coast, is to wash out the boiler, and when refilled with water add two quarts of the cheapest grade of oil, which generally has a fire test of 110° F. Below the suction-pipe of the injector and connected with it by means of a T and two cocks is a well holding about two quarts of the oil. In three or four days this well is filled with oil, and the feed-water passing over the connection gradually displaces the oil and carries it to the boiler, usually taking three or four hours to displace it all. This operation is repeated. Its effect is not to prevent the precipitation of the lime in the water, but to cause it to settle in the form of a loose powder that can be easily blown off.

From a pamphlet on "Oil," by the Standard Oil Company, who prepare "emerald boiler oil," we learn these facts:

"Crude oil is objectionable in that it contains naphtha or volatile properties, which leave in it an element of danger from manipulation; it likewise contains a residual product still more objectionable when inside a boiler.

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* Trans. A. I. M. E., Vol. XVII.

"Kerosene is not open to the same objections, as the volatile properties have been removed in the process of refining; its fire test is not high enough to make it available.

"Illuminating-oil in most States stands 150° F. fire test, while the boiling-point of water or its steam-point is 212° F., which is increased as steam pressure raises.

"Emerald oil when produced does not contain the volatile properties, but is said to retain certain features that assist in scale prevention or removal. Its fire test is high, and there is no danger of formation of a gas at high temperatures, as in the case of kerosene oil. It holds impurities in suspension so that they may be removed by a skimmer. It is said to soften old scale, prevent pitting and corrosion."

Oil should be fed to a boiler drop by drop through a sight-feed or lubricator adapted to the purpose; special oil-feeders, however, have been designed for this purpose.

Mr. Jasper E. Cooper, in an article in *Cassier's Magazine*,* says: "An analysis of a filter deposit from engines without internal lubrication has shown that about 20 per cent of the deposit is fatty matter. This no doubt enters the cylinder and so becomes associated with the steam from piston- and valve-rods. When a number of auxiliary machines are exhausting into the condenser the quantity of oil trapped becomes greater. Engines of the enclosed type, in which the cranks work in a bath of oil, are by far the most troublesome in this respect.

Oil after being deposited in a boiler does not retain its original appearance. It is distilled or burned off, leaving a deposit which from appearances one would say was quite harmless. It is, however, a very poor conductor of heat, and consequently if allowed to remain will very probably cause overheating. One would naturally think that oil, being lighter than water, would remain on the surface; but it is evident that such is not the case. The reason is that the oil, coming in contact with small particles of lime and sticking to them, soon becomes as heavy as the water, and so is circulated about with it until it comes into contact with a tube or plate and sticks to the surface.

In this way the under sides of the tubes are just as liable to

* August 1903, p. 312.

become incrustated as the upper sides, and in the same manner, also, it differs from the ordinary boiler incrustation.

Experiments by Sir John Durston,* 1893, with a fire temperature from 2190° to 2500° F., the temperature of the metal at the bottom of an iron vessel $\frac{1}{2}$ inch thick when the surface was clean was 280° F.; on mixing 5 per cent of mineral oil with the water it rose to 310° F., and when the bottom of the vessel had a coating of grease $\frac{3}{64}$ inch thick it rose to 518° F.

Mineral oils form a brown varnish when deposited in a boiler-plate, are bad conductors of heat and readily cause overheating of the metal.

Bagging of Plates.—Effect of scale in steam-boilers resulting in distortion due to overheating was discussed by C. E. Stromeyer

(Fidelity & Casualty Co.)

FIG. 28.—A Bagged Plate.

before the Inst. of Naval Archs. in 1902. He found, in the case of a flue-boiler where some well-water was used, that the furnace-sheet bulged in two places, and the scale over one bulge not broken through retained the original shape without fracture; steam-pressure was 40 pounds by gauge.

Between the scale and bulged sheet he thinks was superheated steam, which was a bad conductor of heat, allowing the plate to get red-hot. The scale was hard and $\frac{1}{2}$ inch thick.

* Trans. Inst. Nav. Engr., Vol. 34, 130.

A thin film of oil or simply a drop of oil on the sheet may cause bagging by preventing any water from reaching the sheet.

This is one of the baneful results from the use of oil as a scale-preventative or boiler-cleanser.

Extraction of Oil.—A common method for the extraction of oil from condensed high-pressure engine-steam is by adding to the water condensed two substances, which by their combination form a flocculent precipitate, which precipitate is then thoroughly stirred through the water so that it gathers up the fine particles of oil and carries them to the bottom by the subsequent settling.

The cheapest and best substances for this purpose are sodium hydroxide and ferrous sulphate.

This process was patented by C. H. Koyl in 1900.

There are mechanical methods aiming at oil extraction, but they frequently, if not always, leave a trace of oil, as in the results given by the following paragraph:

One case gives 0.07 grain of oil from 58,318 grains of water; another, oil "trace"; another, 0.10 grain of oil from 58,318 grains of water; another, 0.023 grain of oil from 58,318 grains of water. These amounts are credited to the use of the Bundy oil-separator.

Some tests were conducted at the Brooklyn Navy-yard on a 250 H.P. Ball steam-engine, under the direction of Prof. F. R. Hutton, with a "Utility oil-separator" connected to a 12-inch exhaust-pipe between the engine and the surface-condenser; samples of water were taken from the condensed water and steam to find amount of oil still remaining. In the first test 90 per cent of the oil was caught in the separator, and in the mixture of water and oil issuing from the condenser 8 parts per million by weight were oil.

This last statement may not indicate clearly how much oil gets into the boiler if the condensed mixture is used as feed-water.

If a boiler develops 350 boiler horse-power during twelve hours it will have had one pound of oil fed to it in that length of time.

Mr. Chas. Ekstraud says that an experience of fifteen years indicates that the higher the temperature of exhaust steam the less oil can be separated no matter what the device is that is employed.

He uses an open tank with four compartments, filled with hay, charcoal, coke, or other filtering material.

Dividing plates are so arranged that the water flows over one, under the next, and repeats. The air-pump discharges into one end of the tank, water is passed out by gravity at the other end to suction-reservoir of the feed-pump.

Surface-condenser is boiled out with caustic soda annually.

Mr. W. T. Bonner says ammonia-alum type of filters, unless carefully watched, give trouble, and feed-pipes were badly eaten out and tubes badly pitted.

A boiler inspector who has examined a great many boilers using condensed exhaust-steam as part of the feed-water says, that while many separators remove part of the oil returning with the steam "there is still enough left to be very objectionable."

Another says that 4000 separators of one make, in use now, meet the approval of the boiler-insurance company, that is, the water passing through them is allowed as boiler feed-water.

In the Trans. A. S. M. E., Vol. 24, p. 345, an English device called the W. J. Baker separator is described and illustrated.

It is of the closed-tank type, with baffles of wood, and by its use from 98 to 99 per cent of the oil in steam is separated.

Mr. Baker insists on a large area for the steam, reducing its velocity.

Abroad the Rankin, Harris & Edmuston filters are used largely in naval and merchant marine vessels, this last has a mate in this country in the Ross filter, in which coarse towelling is used as the filtering medium.

In an article on "Marine Water Filtering,"* by N. Sinclair, he gives the materials used as turkish towelling and pine sawdust in a wire cage in the water-pipe. For area of the filtering passage the Glasgow Patents Company requires for filters between pump and heater

water	having	3	filtrations,	33	times	area	of	feed-pipe
"	"	2	"	66	"	"	"	"
"	"	1	filtration,	99	"	"	"	"

Another firm thinks 200 times area of feed-pipe for one filtration is needed.

The Reeves Company give 3 inches diameter of chamber for every ½-inch diameter of feed-pipe.

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* Cassier's Mag., Oct. 1897.

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For turkish towelling as a filtering medium, at a common water velocity of 400 to 500 feet per minute, the Glasgow Patents Company rule would give:

for 3 filtrations,	12	to	15	feet	per	minute	through	cloths
" 2 "	6	"	7½	"	"	"	"	"
" 1 filtration,	4	"	5	"	"	"	"	"

Rankine quotes a case as low as 2½ feet per minute through cloths, and others do not give over 2 feet per minute, as in merchant steamship practice.

Oil Separation by Electricity.—This has been accomplished by Messrs. Davis and Perrett of London, Eng.,* by passing the water through a wooden tank 12 feet long, 30 inches wide, and 27 inches deep, the water flowing in parallel streams through the three compartments into which the tank was divided. The flow of water takes place between iron electrodes, maintained at 50 volts potential between adjacent plates, or 150 volts across the three in series.

When this device handled 2000 to 3000 gallons of water per hour it is said to have reduced from 1.07 to 0.01 grain the oil per gallon of water, and at an expenditure of 20 amperes of current. 0.01 grain per English gallon equals 1 part in 7,000,000 by weight.

Use of Crude Oil Under Steam-boilers.—At the meeting of the Southwestern Gas, Electric and Street Railway Association at San Antonio, Tex., in 1902, it was stated that no deleterious effects had been observed from the use of oil where proper care had been exercised in installing and operating the burning apparatus. No extraordinary pitting of tubes and shells had been noted, which may be accounted for by the fact that the amount of sulphur liberated per thousand heat-units is less with oil than with coal. One danger is haste in raising steam from cold boilers. Oil is high in B.T.U.; a large amount can be burned under a boiler in a short time, so boilers equipped in this way are easily forced beyond their rated horse-power and they become more liable to overheating and similar troubles.

Grease and Scale in Boilers.—In a paper before the Institute of Naval Architects by Mr. C. E. Stromeyer, of Manchester, England, on "Distortion in Boilers due to Overheating," he states that a

* Electrical Engineer.

film of grease 0.01 inch thick, a layer of scale 0.1 inch thick, and a steel boiler-plate 10 inches thick offer equal resistance to the passage of heat. In other words, grease offers about one thousand times and scale about one hundred times the resistance of steel plates to the passage of heat, equal thickness being considered. This means also that where the evaporation of 3 pounds of water per square foot of heating-surface per hour requires a difference of only 3° F. between the fire side and the water side of a clean $\frac{1}{2}$-inch furnace-sheet, a layer of scale 0.1 inch thick would necessitate a temperature difference of 60° F. A film of grease would necessitate a still greater temperature difference, and the boiler then would have a greatly diminished efficiency as a steam producer than when its surfaces were clean.

Grease.—Concerning the influence of grease in boilers some curious facts have been developed:

There is no doubt that the introduction of grease will cause furnaces to bulge and tubes to burst, but at the same time an examination of the injured parts shows grease to be absent from them although present in other parts of the boiler.

It would also appear that grease has a more marked effect in otherwise clean boilers than in those covered with scale, and it is far more injurious where forced draft is used than with natural draft.

It is just possible that grease undergoes a chemical change in the boiler, rendering it a far worse conductor of heat than when in its natural state.

Mr. Stromeyer suggests the influence of retarded ebullition and the action of hammer-blows, but collapses due to grease occur gradually, not suddenly. Stromeyer and Barron say the peculiarity of grease deposits in boilers is that their effect is out of all proportion to their thicknesses. We have seen that scale of $\frac{1}{8}$ inch thickness will raise the temperature of furnace-plates about 300° F. As grease offers ten times more resistance to heat, one would expect that $\frac{1}{80}$ inch would have the same effect as this thickness of scale, but experience shows that the merest trace of grease, certainly less than $\frac{1}{1000}$ inch or one-tenth of the above, can cause far more serious injury than scale. Various explanations have been attempted. According to one of these, thin films of grease form tough bubbles on the heating-surface and prevent the water from

keeping it cool. Another view is that the grease, either alone or joined to mineral matter, forms an impalpable powder like oxalate of lime and other precipitates, and, like these, retards ebullition. In support of these views we find a fairly well-founded belief that grease in boilers is more injurious if these boilers are clean than if they are coated with mineral scale, and against this view we have the undoubted experience that land boilers with scale at once give trouble if condensed water is used instead of natural water. Increase of pressure above 110 pounds seems to accentuate this evil; perhaps this may be due to decomposition of magnesium carbonate when this temperature is reached.

In any case it is highly desirable to remove every trace of grease from the feed-water. This cannot be done by filters, and grease-separators which appear to be rather more efficient do not remove the last trace of grease.

Grease in the boilers of the St. Paul, Minn., City Hospital entered, even though a steam-separator was part of the system for preventing this very thing. The sheets of two or three boilers were said to have been badly damaged.

Care of apparatus prevents damage, when careless reliance on machines does not.

To clean a boiler containing too much grease use sal-soda or soda-ash, 10 to 25 pounds to a boiler. Grease and soda form soap, and soap is very readily blown out of a boiler. After soda has been dissolved and put in a boiler, boil up the water, firing until, say, 5 pounds pressure is reached, holding it there for a couple of days, then blow off slowly, cooling gradually. If any grease is left, not enough soda was used or boiling was carried on for too brief a period.

Zinc.—Dr. Kossman says that the use of zinc in boilers for the prevention of scale is useful in selenitic waters, but as against the carbonates of lime, magnesia, and iron is of little value, the zinc being quickly rendered brittle and porous and reduced to a powder.

Dr. G. E. Moore, after analyzing scale and zinc from Sound boats, says the most important results from its use is the protection of the plates, etc., from the hydrochloric acid evolved from the chloride of magnesium of the sea-water. Zinc slabs, blocks, or shavings inclosed in a perforated vessel should be

hung in the water-space throughout its length, the utmost care being taken to insure perfect contact between the zinc and the boiler-shell. Do not place zinc directly over the furnace, as the zinc oxide falling on the crown sheet causes overheating of the sheet.

One square inch of surface of zinc is suggested for every 50 pounds of water capacity in the boiler, but, of course, should be regulated in accordance with the hardness of the water used.

The British Admiralty recommends the renewing of the blocks whenever the decay of the zinc has penetrated to a depth of $\frac{1}{4}$ inch in the slab.

Dr. Corbigny gives this hypothesis: "That the two metals, iron and zinc, surrounded by water at a high temperature form a voltaic pile with a single liquid, which slowly decomposes the water.

"The liberated oxygen combines with the most oxidizable metal, the zinc, and its hydrogen equivalent is disengaged at the surface of the iron. There is thus generated over the whole extent of the iron influenced a very feeble but continuous current of hydrogen, and the bubbles of this gas isolate at each instant the metallic surface from the scale-forming substance. If there is but little of the latter, it is penetrated by these bubbles and reduced to mud; if there is more, coherent scale is produced, which being kept off by the intervening stratum of hydrogen, takes the form of the iron surface without adhering to it."

W. F. Worthington thinks that zinc used in marine boilers has considerable effect in neutralizing the oxygen in the water.

After either cast- or rolled-zinc plates have been suspended in a boiler under steam for some months, the plates are frequently found brittle and to have an earthy fracture; chemical analysis shows that the zinc has been converted to an oxide which must have obtained its oxygen from the water.

3.2 pounds of oxygen in 1 ton of water would require 13 pounds of zinc resulting in ZnO.

In marine boilers, in some instances, the use of zinc plates has been found to cause harder scale and more adherent scale than ever before.

In boilers in which fresh water is used and where calcareous scale forms, giving much trouble, zinc plates have proved ineffectual.

A. M. Hannay devised over twenty years ago a zinc ball with a copper conductor running through it, the copper being amalgamated with the zinc at its junction with it, forming brass, so that no corrosion could form between the metals and shut off the galvanic current.

Galvanic Action.—*Marine Steam*, says: "Formerly nearly all corrosion in boilers was attributed to this cause, and zinc slabs were suspended everywhere possible within the water-space. The position of zinc relative to that of iron in the scale of electro-positive metals causes it to be attacked instead of the metals of the boiler, when galvanic action takes place.

"To afford protection by the use of zinc, however, there must be positive metallic contact between the zinc and iron.

"Practically, it is impossible to maintain this contact with the usual methods of installation, and it has been shown that no galvanic current exists after a few hours of steaming in the arrangements ordinarily employed.

"The use of zinc, however, should not be abandoned on this account as it appears still a very important element of protection against corrosion due to air in feed-water. Its suspension in drums and points within the boiler near the entrance of the feed is recommended as of positive benefit, and, indeed, as long as zinc slabs continue to disintegrate and oxidize in a boiler they deflect to themselves from the iron just that amount of harmful action."

Electrolytic Action.—In the U. S. Navy the rapid destruction of copper piping in several vessels has already caused serious embarrassment, and the reason for this deterioration has not yet been determined to an absolute certainty. As it always happens to a copper pipe, conveying or surrounded by salt water, and as the injection or delivery-pipe to a pump of the coil of a fresh-water distiller is the part attacked, and as the deterioration occurs only in steel ships fitted with dynamos it is thought that the injury may be caused by electrolytic action; for the copper of which the pipes are made is known to be of the very best quality, absolutely free from foreign matter, and therefore not affected by the corrosive action of salt water. In fact, precisely similar pipes made of the same material last almost indefinitely in iron vessels, like the Alert or Ranger, which have no dynamos.

Mr. Chas. H. Haswell was the first to suggest and use the gal-

vanic properties of zinc to prevent corrosion in marine boilers using sea-water. He used zinc thirty years before English engineers advocated its use as a new thing.

Removing Boiler-scale.—Mr. S. M. Green, in *Power*, 1896, says: "I have been using a device that is comparatively new, and I think that a description of the apparatus and the work it has accomplished may be of interest to your readers.

"The device consists essentially of a cylinder of cast iron, about 12 inches in diameter, and of a length varying according to the amount of water to be handled. Contained within this cylinder are a succession of perforated copper and zinc plates, arranged in alternate layers, and through which the feed-water passes. This device was brought to my attention about two years ago, and I was induced to place it upon a plant of four Manning upright boilers, where I had been having some trouble with scale collecting around the base of the tubes, on the crown-sheet. It has now been in active service for about eighteen months, and I have used no scale resolvent of any kind in these boilers. They are absolutely clean. The galvanic action affects the scale, forming properties contained in the water, preventing the formation of scale, but making a deposit in the boiler of soft mud, which is readily removed by blowing and washing.

"In one case the water used is from an artesian well, and is very hard, the analysis showing 31 grains per gallon of solids consisting of calcium sulphate, and carbonate, sodium chloride, magnesium chloride, and organic matter. This water has been used in the boiler for six months, and the boiler is as clean as when new. It has been washed out every six weeks, and all impurities have come out as mud."

Mr. William Thomson, in a paper before the Manchester (Eng.) Society of Engineers, says: "When iron combines with oxygen, as much energy in the form of electricity and heat is liberated as was required to be expended in tearing the two apart in the process of smelting. For rusting to take place it is necessary to have another substance which is electronegative to the iron to be in contact with it, so that the current of electricity liberated by the oxidation of the iron passes away to the metal or other material which acts as the electronegative element. In this way the iron acts as one of the elements of a voltaic cell.

"If you examine a piece of iron which has become corroded by oxidation you will observe that the corrosion has taken place in small holes or pits, and this is technically known as 'pitting.' These are produced by some impurity existing in the iron, which ultimately forms under favorable conditions the center of the pit. This may be a piece of carbon, a minute portion or speck of manganese or other substance, which is electronegative to the iron, which latter being electropositive becomes oxidized. It is curious that when rust begins to form on iron it usually attacks it at certain minute points and extends like spots of mould, the oxide of iron itself acting as an electronegative element to the iron upon which it rests, so that when a piece of iron has become rusty it is very difficult after cleaning to prevent it from again becoming rusty, unless every particle of rust can be most carefully removed from it, each particle forming an electronegative element around and under which the electropositive iron begins to oxidize and produce a small hole or pit."

This is a very clear exposition of the galvanic action produced on iron by other elements.

CHAPTER VII.

HARDNESS OF WATER.

TEMPORARY hardness is that due to calcium and magnesium carbonates held in solution by excess of carbon dioxide in the water. This can be removed by boiling when the carbon dioxide is driven off and the carbonates are precipitated.

Permanent hardness is caused by the presence of magnesium chloride or calcium sulphate, the latter is not precipitated by boiling.

STANDARDS OF HARDNESS.

French. . . . . Milligrams of calcium carbonate in 100 grams of water or parts per 100,000 of water.

German. . . . . Milligrams of lime in 100 grams of water or parts per 100,000 of water.

English. . . . . Grains of calcium carbonate per "imperial" gallon of 70,000 grains.

American. . . . Grains of calcium carbonate per "U. S." gallon of 58,381 grains.

HARDNESS.

Method of Determination of Hardness.—1. *By Soap (Clark's Method).*—When potassium or sodium soap is added to water containing calcium and magnesium salts the soap is decomposed and insoluble compounds with the fatty acids are produced.

Upon this decomposition of soap is based the method for the determination of "lime salts" which was perfected and patented by Thomas Clark * in 1841. Variously modified by French, German, and English chemists, the principles formulated proved of

* Clark's Process, Repertory Patent Inventions, 1841.

general application. He employed sixteen standard calcium-carbonate solutions, containing from one to sixteen "degrees of hardness," one degree meaning one grain of calcium carbonate to the imperial gallon. The soap solution was prepared by dissolving hard soap in proof spirits and making up to such a strength that 100 test measures of the standard calcium-carbonate solution of 16 degrees of hardness should take 32 test measures of soap solution, a test measure being $\frac{1}{7000}$ part of a gallon.

Hardness may be temporary, caused by the presence of bicarbonates which are decomposed by boiling heat, with the liberation of carbon dioxide (carbonic acid), or permanent, caused by compounds other than the bicarbonates. In the Clark process the total hardness is determined on the unboiled water and the permanent on the boiled, the difference being the temporary hardness. The total hardness only is given in the results tabulated in the State Board of Health Reports.*

The solutions used in the laboratory for water analysis are made as follows:

A standard calcium-chloride solution is prepared by dissolving 0.2 gram of Iceland spar in dilute hydrochloric acid in a platinum dish and evaporating to dryness, redissolving in a small amount of water and again evaporating to dryness. This is repeated several times, until all the free acid is removed and a perfectly neutral salt remains, which is dissolved in water and made up to one liter. One cubic centimeter then contains calcium-chloride equivalent to 0.0002 gram calcium carbonate.

For the preparation of the standard soap solution 100 grams of the best quality of dry white castile soap is cut into thin shavings dissolved in dilute alcohol (500 cubic centimeters 96 per cent alcohol and 500 cubic centimeters of distilled water) and allowed to stand overnight to settle; 100 cubic centimeters of the clear liquid are then made up to 2 liters, enough alcohol being used to keep all of the soap in solution. 50 cubic centimeters of the standard solution of calcium chloride, which, according to the table, should take exactly 14.25 cubic centimeters of standard soap, are used to test its strength. The solution thus prepared does not change perceptibly if air has no access to it, and if used

* Mass. State. Board of Health, 37th Annual Report.

with a siphon burette attached to the bottle will keep for five or six weeks or longer. It contains 5.2 grams of castile soap to the liter.

For the standardization of the soap and for the determination of the hardness of any water, 50 cubic centimeters of the water to be tested or of the standard calcium-chloride solution are placed in a flask or bottle of 200 cubic centimeters capacity and of a convenient shape, and the soap solution added, two or three-tenths of a cubic centimeter at a time, shaking well after each addition, until a lather is obtained which is permanent for five minutes and covers the entire surface of the liquid with the bottle placed on its side.

The table opposite gives the hardness corresponding to the number of cubic centimeters of soap solution used in the analyses.

The importance of adding the soap solution in small quantities cannot be too strongly emphasized, especially in the presence of magnesium compounds. If much carbonic acid be liberated, it is well to follow the original directions and remove it by suction. It will be observed that the table does not admit of the determination of hardness above 12.5 parts. In case the water under examination requires more than 10 cubic centimeters of the standard soap solution, a smaller portion of 25 cubic centimeters, 10 cubic centimeters, or even 2 cubic centimeters, as the case may require, is measured out and made up to a volume of 50 cubic centimeters with recently distilled water. This will keep the results comparable with each other, although the element of dilution introduces a slight error into the calculation.

2. *By Acid (Hehner's Method).*—Attempts have been made to determine the calcium and magnesium salts by means of standard acid and alkaline solutions instead of by soap. An exhaustive study of the relative practical value of one of these, as compared with the soap method, was made in 1890 in the laboratory of the Massachusetts State Board of Health. A condensed summary of the results is given on pages 147 and 148.

The standard solutions used are sodium carbonate, 1.06 grams to the liter, 1 cubic centimeter corresponding to 0.0001 gram calcium carbonate, and sulphuric acid of such a strength that 1 cubic centimeter will exactly neutralize 1 cubic centimeter of

the standard sodium carbonate (0.98 gram of sulphuric acid to 1 liter).

TABLE OF HARDNESS IN PARTS PER 100,000, 50 CUBIC CENTIMETERS OF WATER USED.

C.c. of Soap Solution.	$CaCO_3$ per 100,000.	C.c. of Soap Solution.	$CaCO_3$ per 100,000.	C.c. of Soap Solution.	$CaCO_3$ per 100,000.	C.c. of Soap Solution.	$CaCO_3$ per 100,000.	C.c. of Soap Solution.	$CaCO_3$ per 100,000.
.7	.00	3.8	4.29	6.9	8.71	10.0	13.31	13.1	18.17
.8	.16	.9	.43	7.0	.86	.1	.46	.2	.33
.9	.32	4.0	.57	.1	9.00	.2	.61	.3	.49
1.0	.48	.1	.71	.2	.14	.3	.76	.4	.65
.1	.63	.2	.86	.3	.29	.4	.91	.5	.81
.2	.79	.3	5.00	.4	.43	.5	14.06	.6	.97
.3	.95	.4	.14	.5	.57	.6	.21	.7	19.13
.4	1.11	.5	.29	.6	.71	.7	.37	.8	.29
.5	.27	.6	.43	.7	.86	.8	.52	.9	.44
.6	.43	.7	.57	.8	10.00	.9	.68	14.0	.60
.7	.56	.8	.71	.9	.15	11.0	.84	.1	.76
.8	.69	.9	.86	8.0	.30	.1	15.00	.2	.92
.9	.82	5.0	6.00	.1	.45	.2	.16	.3	20.08
2.0	.95	.1	.14	.2	.60	.3	.32	.4	.24
.1	2.08	.2	.29	.3	.75	.4	.48	.5	.40
.2	.21	.3	.43	.4	.90	.5	.63	.6	.56
.3	.34	.4	.57	.5	11.05	.6	.79	.7	.71
.4	.47	.5	.71	.6	.20	.7	.95	.8	.87
.5	.60	.6	.86	.7	.35	.8	16.11	.9	22.03
.6	.73	.7	7.00	.8	.50	.9	.27	15.0	.19
.7	.86	.8	.14	.9	.65	12.0	.43	.1	.35
.8	.99	.9	.29	9.0	.80	.1	.59	.2	.51
.9	3.12	6.0	.43	.1	.95	.2	.75	.3	.68
3.0	.25	.1	.57	.2	12.11	.3	.90	.4	.85
.1	.38	.2	.71	.3	.26	.4	17.06	.5	22.02
.2	.51	.3	.86	.4	.41	.5	.22	.6	.18
.3	.64	.4	8.00	.5	.56	.6	.38	.7	.35
.4	.77	.5	.14	.6	.71	.7	.54	.8	.52
.5	.90	.6	.29	.7	.86	.8	.70	.9	.69
.6	4.03	.7	.43	.8	13.01	.9	.86	16.0	.86
.7	.16	.8	.57	.9	.16	13.0	18.02		

Clark was the first to introduce the term "degree of hardness," and in Table No. 1 each measure of soap solution = 10 grains and each degree of hardness = 1 grain of carbonate of lime or its equivalent of another calcium salt, or equivalent quantities of magnesia or magnesium salts in 70,000 parts (= 1 gallon English).

For the determination of the temporary hardness, 100 cubic centimeters of the water to be tested, tinted with lacmoid, which is the best indicator to use with surface waters, are heated in a porcelain dish nearly to boiling and the standard acid added to a

neutral reaction. Each cubic centimeter of acid corresponds to one part of calcium carbonate per 100,000.

For the permanent hardness another 100 cubic centimeters of water are taken and enough of the standard sodium-carbonate solution added to more than decompose the salts of calcium and magnesium and the whole evaporated to dryness in a platinum or nickel dish. (Glass and porcelain cannot be used, as too large an error is introduced from the alkali dissolved from these substances.) The residue is first treated with boiling distilled water which has been boiled for a few minutes to remove any carbonic acid, then filtered through a small filter, which must be well washed, the filtrate tinted with lacmoid, and the excess of free alkali determined by the standard acid.*

The number of cubic centimeters of sodium carbonate used, less the acid used for neutralization, gives the permanent, and the sum of the two gives the total, hardness.

With alkaline waters, with sewage, and with some sewage effluents a correction must be made for the excess of alkaline carbonates; but in these cases the results after correction do not compare as closely with the soap method as do those obtained with the natural waters.

The results given in the table opposite were obtained by the two methods, which were tried on a number of ground- and surface-waters and several samples of sewage, in every case the total hardness being given.

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* Analyst, Vol. VIII, p. 77, 1883.

SURFACE-WATERS.

(Parts per 100,000.)

(Report Mass. St. Board of Health.)

Place of Collection.	Total Hardness by Soap.	Total Hardness by Acid.
Fitchburg, Overlook Reservoir	0.48	0.70
Springfield, Ludlow Reservoir, 6 feet beneath the surface.	0.79	1.11
" " " at surface	0.79	1.00
Quincy, reservoir	0.79	0.80
Lawrence, Merrimac River	0.80	1.11
Brockton, reservoir	0.90	0.80
Quincy, inlet to reservoir	0.95	0.70
Worcester, Holden Reservoir	0.95	1.10
Millville, Blackstone River	1.10	1.50
Boston Water-works, Basin 4, 20 feet beneath the surface	1.11	1.11
" " " 4, 4 " " " "	1.27	1.00
Lawrence, Merrimac River	1.30	1.60
Boston Water-works, Cold Spring Brook, at head of Reservoir No. 4	1.43	1.40
Boston Water-works, Reservoir No. 2	1.46	1.45
" " Sudbury River, at head of Reservoir No. 2	1.56	1.30
Boston Water-works, Reservoir No. 4, near bottom	1.56	1.55
" " " " 3	1.80	1.90
Framingham, farm pond	1.95	1.90
Marlborough	2.30	2.00
Boston Water-works, Stony Brook, at head of Reservoir No. 3	2.34	2.35
Winchester, reservoir	2.60	2.70
Worcester, Blackstone River	2.86	2.90
Poughkeepsie, inlet of filter-basin	4.00	4.00
" " " east filter-bed	4.00	4.00
" " " west "	4.00	4.00
" Hudson River	4.57	4.50

The following two methods were then tried upon three samples of sewage, the results of which show wide differences:

Place of Collection.	Total Hardness by Soap.	Total Hardness by Acid.
No. 1	4.20	5.80
" 2	3.90	7.20
" 3	3.60	5.60

The above three samples were strongly alkaline, in every case the acid method giving the higher results.

GROUND-WATERS.

Place of Collection.	Hardness by Soap.	Hardness by Acid.	Place of Collection.	Hardness by Soap.	Hardness by Acid.
Whitman, well.	1.80	1.70	Woburn, well.	4.90	4.40
Whately, well.	2.08	2.00	Winchester, well. ...	5.10	6.80
South Deerfield, well.	2.21	1.95	Hatfield, well.	5.14	4.70
Melrose, well.	2.30	2.40	South Deerfield, well.	5.71	5.40
" "	2.50	3.20	" " "	5.71	5.42
Greenfield, well....	2.73	2.20	Hatfield, well.	6.00	6.30
Melrose, well.	2.90	3.50	Williamsburg, well. .	6.29	8.80
Framingham, filter-basin.	3.10	3.10	Winter Hill, well. ...	7.00	7.70
Orange, well.	3.40	3.40	Malden, well.	7.10	7.30
Melrose, well.	3.50	4.70	South Framingham, underdrain.	7.70	7.70
Reading, well.	3.60	4.90	Malden, well.	7.90	8.80
Malden, well.	3.60	5.60	Reading, well.	10.00	10.10
Cambridge, well. ...	4.20	5.80	Framingham, well. ..	10.10	9.80
" "	4.40	4.90	Reading, well.	11.50	10.50
Boston, well.	4.40	4.90	Amherst, well	12.56	12.30
Williamsburg, well. .	4.57	4.20	Williamstown, spring	34.40	30.35
Reading, well.	4.60	4.50	Chelsea, well	17.30	17.10
Saugus, well.	4.70	6.30	" "	17.50	17.40
Amherst, well.....	4.71	4.45	Williamstown, well. .	34.40	30.35

Hard water can always be told on account of the difficulty in making lather with soap in it. The following table gives the amount of soap required to produce a permanent lather in waters of varying degrees of hardness:

Degrees, Hardness.	Pounds Soap Destroyed per 1000 Gallons of Water.	Cost of Soap at 5 Cents per Pound.
5	8.5	$0.41
10	17.0	0.82
15	25.5	1.23
20	34.0	1.64
25	42.5	2.05

Coagulation by means of alum in mechanical filtration causes some of the carbonate of lime to change to sulphate of lime, setting free carbonic acid, which causes corrosion of the metal of boilers, though it can be obviated by the use of a good protective coating on the metal. The sulphate of lime in steam-boilers results in a scale which attaches itself much more firmly to the boiler surfaces than the carbonate does.

	Raw River-water.	Filtered Water.
Temporary hardness (alkalinity).	23	15
Permanent hardness (incrusting properties). . .	12	19
Total hardness.	35	34

From the above table it will be seen that filtration, the object of which is pure drinking-water, adds seven points to the incrusting properties in the water, and from other sources we learn that 96.5 to 99.1 per cent of the bacteria are removed by the same process.

Naturally we would expect more scale and corrosion in the boilers of steam-plants in towns using alum in purifying water.

A water of which the hardness is entirely "temporary," that is due to the carbonate of lime and carbonate of magnesia, can be softened with lime alone, which costs, say, $5 per ton or less; but "permanent" hardness, due to sulphate of lime, can be removed only by using alkali, costing at present prices (in 1898) $25 per ton. Less than one pound of lime per 1000 gallons of water will remove 10 degrees of temporary hardness, but 1.6 pounds of alkali is required for the removal of 10 degrees of permanent hardness due to sulphate of lime, while sulphate of magnesia is still more expensive to remove.

Taking quicklime at $5 a ton and alkali at $25 per ton, the cost * of chemicals for softening water is about as follows per thousand gallons:

For every 10 degrees of temporary hardness. . . . . 0.22 cents
" " 10 degrees " permanent " . . . . . 1.90 "

Thus permanent hardness is about nine times as expensive to remove as temporary hardness.

Sulphates.—A quick method for determining the sulphates in water, with sufficient exactness for boiler purposes, is one making use of the Jackson † candle turbidimeter.

* Leonard and Archbutt, Inst. Mech. Engrs., 1898.

† D. D. Jackson, Dir. Mt. Prospect Laboratory, Brooklyn, N. Y.

The original form of the instrument was first described by its inventor in the Journal of the Amer. Chem. Soc., Nov., 1901 but since that time it has been considerably improved upon.

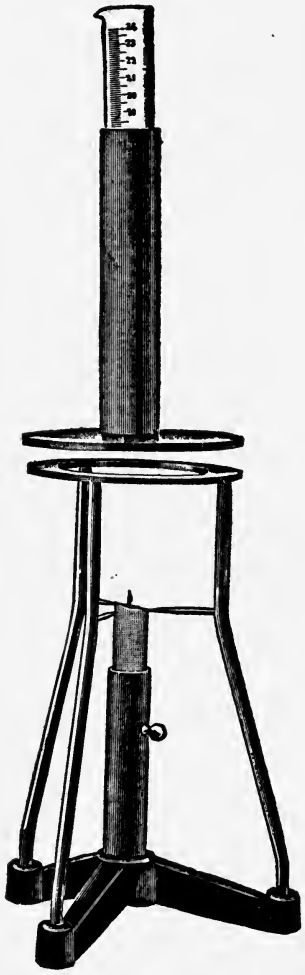

FIG. 28a.—Jackson Turbidimeter.

The accompanying illustration gives a good idea of the present form of the instrument and its use. The apparatus consists of a glass tube closed at the bottom and graduated in centimeters and millimeters depth. This is surrounded by a brass holder open at the bottom and supported by a stand in the center of which is a standard English candle so adjusted that its top rim is just 3 inches below the bottom of the glass tube.

This instrument is very convenient for use in the laboratory, and as its source of light is the standard candle, it is ready at all times.

Read the depth of the liquid (using the bottom of the meniscus in reading). Refer this reading to the table opposite to obtain the parts per million or grains per gallon.

A convenient form of tube is a Nessler jar 2.5 cm. in diameter and 17 cm. to the 100-c.c. mark. The brass holder for this tube is open at the bottom so that the glass tube rests on a narrow ring at this point. The candle below is so adjusted by means of a spring that the top edge is always just 3 inches below the bottom of the glass tube. The illustration shows the candle with the regulator cap removed so as to better represent the process. The English standard candle is preferred, but a common candle of the same size may be used. This candle must always be properly trimmed and the determination must be made

TABLE FOR CONVERTING READINGS IN DEPTHS BY THE TURBIDIMETER INTO PARTS PER MILLION OR GRAINS PER GALLON OF SULPHATE. (JACKSON.)

Reading in Centimeters.	Parts per Million (SO_3).	Grains per U. S. Gallon (SO_3).	Reading in Centimeters.	Parts per Million (SO_3).	Grains per U. S. Gallon (SO_3).	Reading in Centimeters.	Parts per Million (SO_3).	Grains per U. S. Gallon (SO_3).
1.0	520	30.5	5.4	104	6.1	10.8	53	3.1
1.1	480	28.0	5.5	103	6.0	11.0	52	3.1
1.2	440	25.5	5.6	101	5.9	11.2	51	3.0
1.3	410	24.0	5.7	99	5.8	11.4	50	3.0
1.4	385	22.5	5.8	97	5.7	11.6	49	2.9
1.5	360	21.0	5.9	96	5.6	11.8	48	2.8
1.6	340	20.0	6.0	94	5.5	12.0	47	2.7
1.7	320	18.5	6.1	93	5.4	12.4	46	2.7
1.8	300	17.5	6.2	91	5.3	12.6	45	2.6
1.9	285	16.5	6.3	90	5.2	12.8	44	2.6
2.0	275	16.0	6.4	88	5.1	13.0	43	2.5
2.1	260	15.0	6.5	87	5.1	13.5	42	2.5
2.2	250	14.5	6.6	86	5.0	14.0	41	2.4
2.3	240	14.0	6.7	84	4.9	14.5	39	2.3
2.4	230	13.5	6.8	83	4.9	15.0	38	2.3
2.5	220	13.0	6.9	82	4.8	15.5	37	2.2
2.6	215	12.5	7.0	81	4.8	16.0	36	2.1
2.7	205	12.0	7.1	80	4.7	16.5	35	2.0
2.8	200	11.7	7.2	79	4.7	17.0	34	2.0
2.9	190	11.1	7.3	78	4.6	17.5	33	1.9
3.0	185	10.8	7.4	77	4.5	18.0	32	1.9
3.1	180	10.5	7.5	76	4.4	18.5	31	1.8
3.2	175	10.2	7.6	75	4.4	19.0	30	1.8
3.3	170	9.9	7.7	74	4.3	20.0	29	1.7
3.4	165	9.6	7.8	73	4.3	21.0	28	1.7
3.5	160	9.4	7.9	72	4.2	22.0	27	1.6
3.6	155	9.1	8.0	71	4.2	22.5	26	1.6
3.7	150	8.8	8.1	70	4.1	23.0	25	1.5
3.8	147	8.6	8.2	69	4.0	24.0	24	1.4
3.9	144	8.4	8.3	68	4.0	25.0	23	1.3
4.0	140	8.2	8.5	67	3.9	26.5	22	1.3
4.1	137	8.0	8.6	66	3.9	28.0	21	1.2
4.2	133	7.8	8.7	65	3.8	29.0	20	1.2
4.3	131	7.7	8.8	64	3.8	31.0	19	1.1
4.4	128	7.5	9.0	63	3.7	33.0	18	1.1
4.5	125	7.3	9.1	62	3.7	35.0	17	1.0
4.6	122	7.1	9.3	61	3.6	37.5	16	1.0
4.7	119	7.0	9.5	60	3.6	40.0	15	0.9
4.9	117	6.8	9.7	59	3.5	43.0	14	0.9
4.9	115	6.7	9.8	58	3.4	46.5	13	0.8
5.0	113	6.6	10.0	57	3.3	50.0	12	0.7
5.1	110	6.4	10.2	56	3.3	55.5	11	0.6
5.2	108	6.3	10.4	55	3.2	62.0	10	0.6
5.3	106	6.2	10.6	54	3.2	68.0	9	0.5

rapidly so as not to heat the liquid to any extent. The most accurate work is obtained in the dark-room, and the candle should be so placed as not to be subjected to a draft of air. Care should be taken to keep the bottom of the tube clean both inside and out so as not to cut out any of the light.

Mr. Jackson gives this method for the determination of sulphates.

It has been found that by means of this instrument other determinations than turbidity may be made. If the water is clear or is clarified by a filter, a determination of the sulphate present in the water may be obtained.

Determination of Sulphate in Water by Means of the Turbidimeter.

The amount of sulphate in natural waters is important on account of the scale-forming action of sulphate of lime in waters used for boiler purposes. If the amount of sulphate is considerable the determination may be made by the turbidimeter with a fair degree of accuracy. The method is as follows:

To 100 c.c. of the water to be tested add 1 c.c. of hydrochloric acid (1–1) and 1 gram of solid barium chloride crystals. If the amount of sulphate is low 200 or 300 c.c. of water must be treated in order to fill the longer tube employed. In this case add 1 c.c. of acid and 1 gram of barium chloride for each 100 c.c. of water taken.

Allow the mixture to stand for ten minutes with frequent shaking. The shaking is best accomplished if the water is treated in a bottle. The barium sulphate will be precipitated in a finely divided state and the turbidity produced is then read by pouring the milky solution into the glass tube and noting the point at which the image of the candle disappears.

The determinations as made by this method are extremely rough and are mainly used for approximate figures, obtained quickly, and with little labor.

Calcium.—To determine the calcium, the water is rendered slightly ammoniacal and a small quantity of ammonium oxalate crystals is added.

When the calcium oxalate is precipitated, and the turbidimeter as above is used, the equivalent calcium may be found by reference to this table.

TABLE FOR ESTIMATION OF CALCIUM IN WATER IN PARTS PER MILLION WITH JACKSON TURBIDIMETER.

Depth.	Calcium Equivalent.	Depth.	Calcium Equivalent.	Depth.	Calcium Equivalent.	Depth.	Calcium Equivalent.
1.0	1150	4.1	162	7.2	77	10.6	50
1.1	1000	4.2	156	7.3	76	10.8	49
1.2	890	4.3	151	7.4	74	11.0	48
1.3	795	4.4	146	7.5	73	11.2	47
1.4	715	4.5	142	7.6	72	11.4	46
1.5	650	4.6	137	7.7	71	11.7	45
1.6	595	4.7	133	7.8	70	11.9	44
1.7	550	4.8	130	7.9	69	12.2	43
1.8	505	4.9	126	8.0	68	12.4	42
1.9	470	5.0	123	8.1	67	12.7	41
2.0	435	5.1	119	8.2	66	13.0	40
2.1	410	5.2	116	8.3	65	13.3	39
2.2	380	5.3	113	8.4	64	13.7	38
2.3	360	5.4	110	8.5	64	14.0	37
2.4	340	5.5	107	8.6	63	14.4	36
2.5	320	5.6	105	8.7	62	14.8	35
2.6	305	5.7	102	8.8	61	15.3	34
2.7	288	5.8	100	8.9	60	15.7	33
2.8	274	5.9	98	9.0	60	16.2	32
2.9	261	6.0	96	9.1	59	16.7	31
3.0	248	6.1	94	9.2	58	17.3	30
3.1	238	6.2	92	9.3	57	17.9	29
3.2	228	6.3	90	9.4	57	18.5	28
3.3	218	6.4	88	9.5	56	19.2	27
3.4	209	6.5	87	9.6	55	20.0	26
3.5	200	6.6	85	9.7	55	20.8	25
3.6	194	6.7	84	9.8	54	21.7	24
3.7	186	6.8	82	9.9	54	22.7	23
3.8	179	6.9	81	10.0	53	23.8	22
3.9	173	7.0	80	10.2	52	24.0	21
4.0	167	7.1	78	10.4	51	25.2	20

CHAPTER VIII.

FEED-WATER HEATERS.*

THE time to purify all boiler feed-water is before it ever gets to the boiler, never in the boiler. It is very much more desirable that one has a lot of trouble keeping feed-water heaters and purifiers clean than to have the stuff get in the boiler.

A new "tray" heater was put in a Pennsylvania power-plant not so long ago, and when the steam-engineer was asked how it suited him he said that there was entirely too much "stuff" on the trays; in fact, it necessitated his cleaning them every day, which was not the condition of things with his old heater.

Here was an absolute lack of recognition of the great benefit to the boiler, in that purer water would give the boiler a longer life and a higher rate of evaporation, less liability to explosion, and altogether resulting in a much more economical steam-plant and a much less expense account.

When we were considering the treatment of water chemically, we had in mind only that one general method of preparation and purification.

Boiler feed-water is derived from two general sources, namely:

a. New water supplie .

b. Condensed steam.

The first, *a*, may be treated or untreated water, and be simply passed through a tubular-feed heater, where certain impurities insoluble at, say, 210° F., will separate out and settle to the mud-drum of the heater, leaving the other substances in solution, which are still more harmful to the boiler.

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* A considerable portion of this chapter appeared originally as an article on "Feed-water Heaters" in *Cassier's Magazine* in 1903.

The second, *b*, is that derived from condensed steam of any kind, as from drips or water from a surface-condenser.

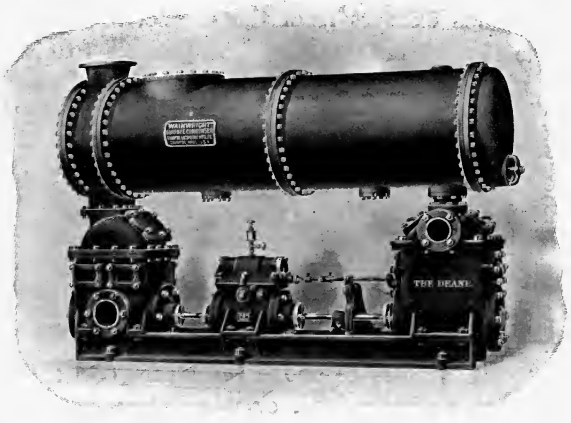


FIG. 29.—Wainwright Surface-condenser.

This water may be passed through a feed-heater and purifier on its way to the boiler, where there is any likelihood of the presence of oil in the condensed water it should be passed through an oil-separator or filter—this also applies to condensed steam from engines which may or may not have been through a tubular feed-heater.

FEED-WATER HEATERS.

The writer would classify feed-water heaters thus:

Closed heaters (indirect).....	{ Steam-tube. Water-tube.
Open heaters (direct).....	{ Atmospheric. Vacuum.
Flue-gas heaters.....	Economizers.

Closed heaters are those in which the steam to be utilized is separated from the water by a metal wall, usually copper or brass, as pipes, which material is the most desirable. This type of heater is used where the water is least contaminated, and is considered a good feed-water.

The efficiency of these heaters is a direct function of the ability of the metal walls to transmit the heat from the steam to the water and the amount of circulation or breaking up which the water receives in passing through the heater. In cases where the steam used is exhaust from the engine, and at atmospheric pressure, the highest temperature it is possible to give the feed-water is 210° to 212° F.

Sheet-iron or steel shells are used for the steam-tube heaters, with water going through the shell under boiler pressure; cast iron is used for the shells of water-tube heaters, as it is less liable to galvanic action and pitting from grease and action of water and steam in the shell.

The water-tube type of the closed heater is one which gives the same heating-surface in less space than is possible in the steam-tube type.

In the closed heaters as above the steam condensing in them is a total waste as boiler-feed, or when clean hot water can be utilized, unless it is passed through a filter which will remove the oil and other matters in suspension.

Open heaters are those into which the steam is exhausted in direct contact with and intermingling with the water.

They are especially useful where the water is full of lime and other scale-forming elements; they are fully equipped with devices for aiding the precipitation of the salts, and separating and filtering out the oil, delivering a pure boiler feed-water.

This type of heater may be so controlled in its action as to have the water take up all the heat in all the steam, and may raise the temperature of the water to slightly beyond 212° F.

Two things are very essential to the successful working of all heaters: they must be kept clean and sufficient exhaust steam be sent to them to furnish the necessary heat or the water regulated so as not to lower the temperature in the heater below 212° F.

Of the many heaters on the market a few representative designs are shown and their features described.

The Patterson-Berryman water-tube heater, Fig. 30, is of the pressure type, and consists of an iron shell and setting-chamber with U-shaped brass tubes expanded in a heavy cast-iron tube-head. In this type the water passes in and through a nest of tubes, and then, owing to partitions set in the settling-chamber, clearly

seen in the sketch, the water passes through another nest of tubes and finally out to the boiler. The steam is exhausted into the

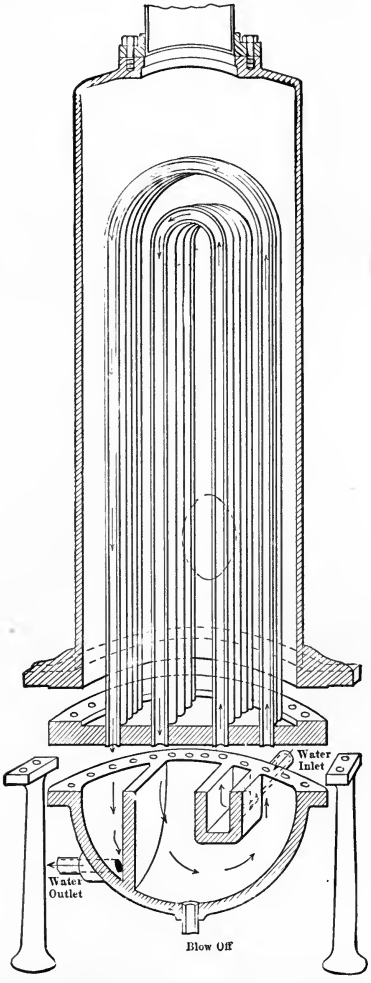


FIG 30.—Sectional View of the Patterson-Berryman Heater.

steel and outside of the nests of tubes, and usually the steam passes out at the top to the atmosphere or elsewhere as desired.

The Goubert heater, Figs. 31 and 32, is another of the pressure type which has had a large field of usefulness. The water in en-

tering the heater passes through a sleeve against a saucer-like deflector, then down into a mud-drum, and finally up through the tubes, each tube-end being expanded into curved or dished flue-

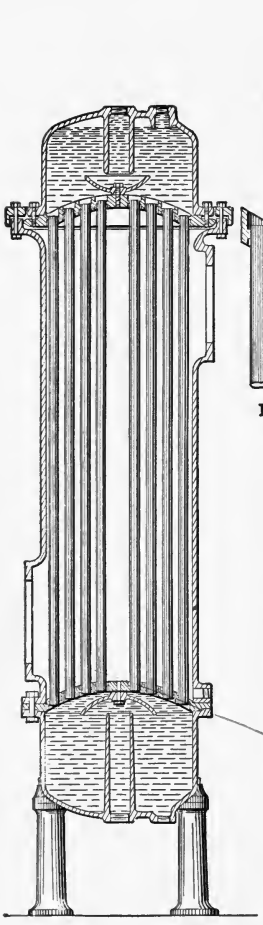

Water Chamber
Tube Plate
Differential Expansion between Tube and Shell 1/16 of an inch in 10 feet
Enlarged View of Expansion Joint

FIG. 31.—Section of the Goubert Heater.

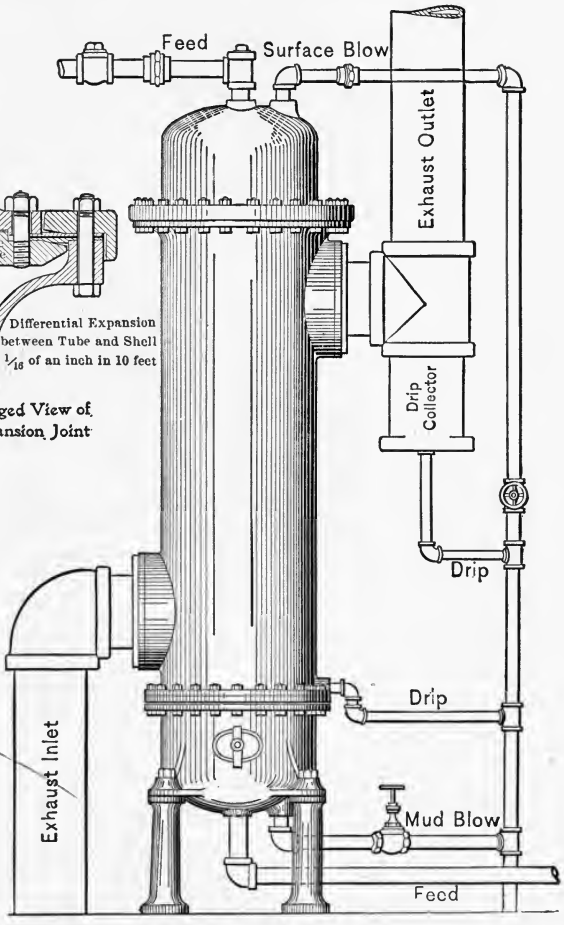
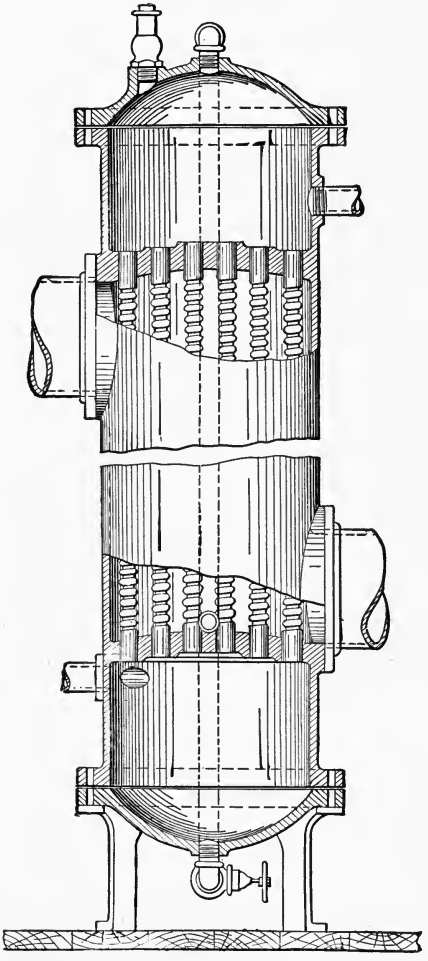


FIG. 32.—Elevation of a Goubert Heater and Connections.

heads. The upper water-chamber is an invert of the lower one. A feature of this heater is a flexible joint between the outer shell and inner tubes and their bonnet at the top. This joint is made up of a loose flange, three gaskets, one of soft annealed copper and

two of special packing with wire cloth impeded in them, and the flange which is a part of the cast-iron body of the heater.

The Wainright heater, Fig. 33, is of the closed type, and is made



(The Taunton Locomotive Co., Makers.)

FIG. 33.—The Wainwright Heater.

with steam-tubes or water-tubes, and is built either vertical or horizontal, a remark applying to practically all closed heaters.

The special feature of this heater is the tubes, which are of brass

and corrugated, and also in the use of a long shell or body of comparatively small diameter rather than a short shell of large diameter.

The water-spaces are so designed that they may give an even flow at a rapid rate of travel, which aids materially a high rate of convection of heat through the tubes to the water.

Tests made of heaters having different types of tubes tend to show that if water is broken up and travels at a rapid rate of speed it will take the greatest number of heat-units from the steam per unit of time. The cold core or zone in a body of water passing through a straight tube having parallel sides is found by experiment to give way to a more evenly heated body of water in the

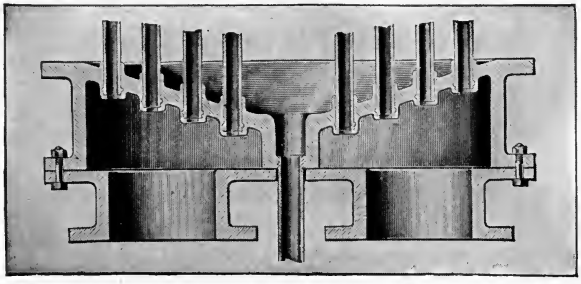


FIG. 34.—Section of Tube-plate, Bottom of Davis-Berryman Heater.

corrugated tube, because of the more thorough mixing resulting from the presence of the corrugations on the tube.

In the Davis-Berryman heater the body is made of "shell steel" and the head of "flange steel." The tubes, tested to 500 pounds per square inch, are bent ∩ shape and expanded into a cast-iron tube-head.

This head is conical, as shown by Fig. 34, aiding the sediment to pass immediately to the discharge mud-blowpipe outlet.

This is the steam-tube type, with the water-inlet high enough at the side not to disturb the sediment, and the water-outlet is at the proper distance below the top level of the water to prevent the scum going over with the water. A valve is provided for the removal of scum.

One of the many forms of Baragwanath heaters is known as a steam-jacket heater.

The tubes, as shown in Fig. 35, are expanded into tube-sheets at top and bottom. The exhaust steam enters at the bottom, passes up through the tubes and returns on the outside of the inner shell, the water being between the pipes and the inner shell.

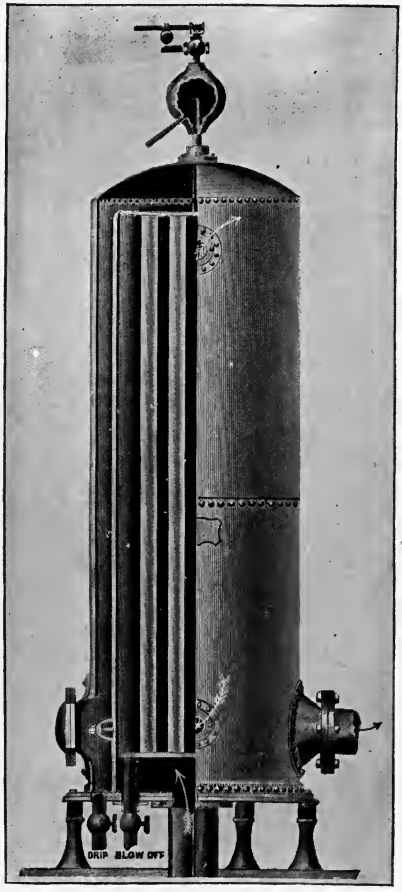


FIG. 35.—Baragwanath Steam-jacket Heater.

The water-inlet is at the bottom of the shell and the outlet at the top. The same makers build a horizontal open heater with a screen for separation of oil and trays for sedimentation.

In the Wheeler heater, Fig. 36, there are tube-heads at both ends; the tubes are enlarged at one end and made fast by a screw

end. The other end is made fast by a brass outer ferrule and asbestos packing, which go in a special pocket formed in the tube-head for the purpose.

The tubes are free to expand or contract as the ferrule is not

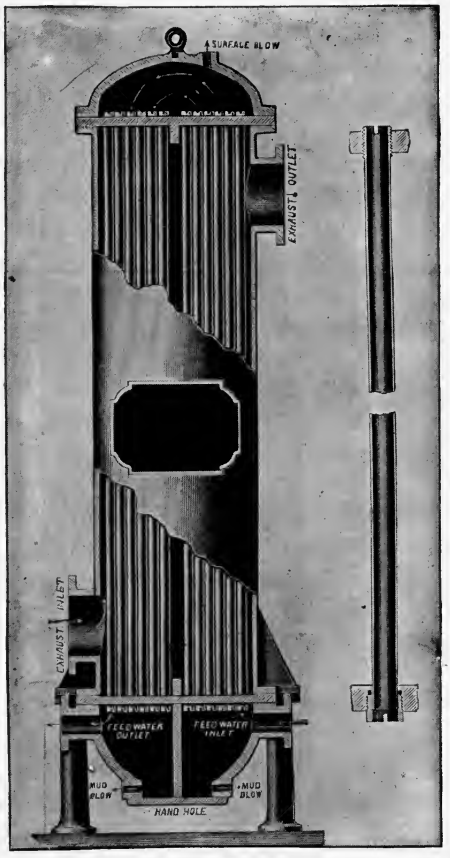


FIG. 36.—Heater made by the Wheeler Condenser and Engineering Co.

rigidly attached to the tube. These heaters are also made at both ends of the tubes with ferrule and asbestos packing.

The quality of the tubes is the best seamless brass, tinned and tested to 700 pounds pressure per square inch.

The same company make a double-tube horizontal heater for marine service. The exhaust steam in this type passes through

the inner tubes, then returns through the annular space between them and the larger tubes, and then is exhausted.

The feed-water enters the shell at the bottom and travels between and about the exterior of the tubes and then out at the top and to the boilers.

One of the early designs of feed-water heaters is of the coil type. This was developed in Great Britain, and is virtually an enlarged exhaust pipe; in fact, it is a portion of the length of the exhaust pipe, from the top of which cast-iron body drops a perpendicular feed-water pipe having a copper-coil pipe winding upward from its lower end and out through the top head, as shown in Fig. 37.

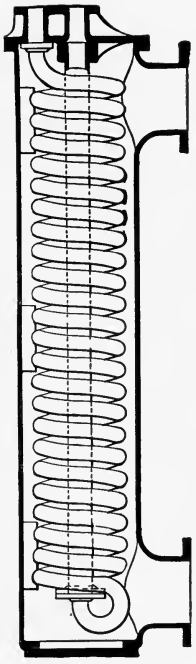
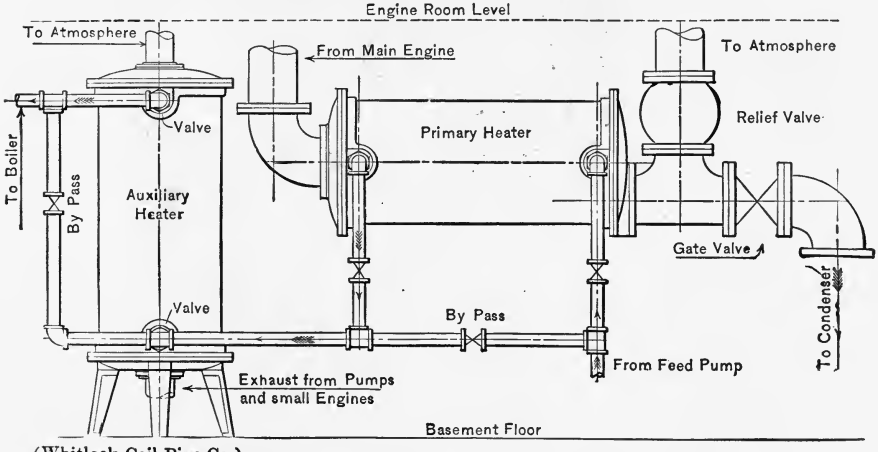


FIG. 37. — Copper-coil Heater by Yates and Thom, England.

If the feed-water is pure this would prove a very desirable heater, as its principle of long travel of water in ample steam-space is good.

The American development of this heater is shown in another line of water-tube heaters, consisting of copper or brass coils bent spirally and set inside a riveted-steel, cast-iron, or steel shell.

The Whitlock, Fig. 38, is so built and con-



(Whitlock Coil Pipe Co.)

FIG. 38.—Arrangement of Primary and Auxiliary Heaters.

sists of a steel-shell body, riveted to cast-iron flanges top and bottom to which the heads are bolted. Inside of this heater, all of whose shell-joints are brazed, are copper coils, tested before use to 600 pounds per square inch.

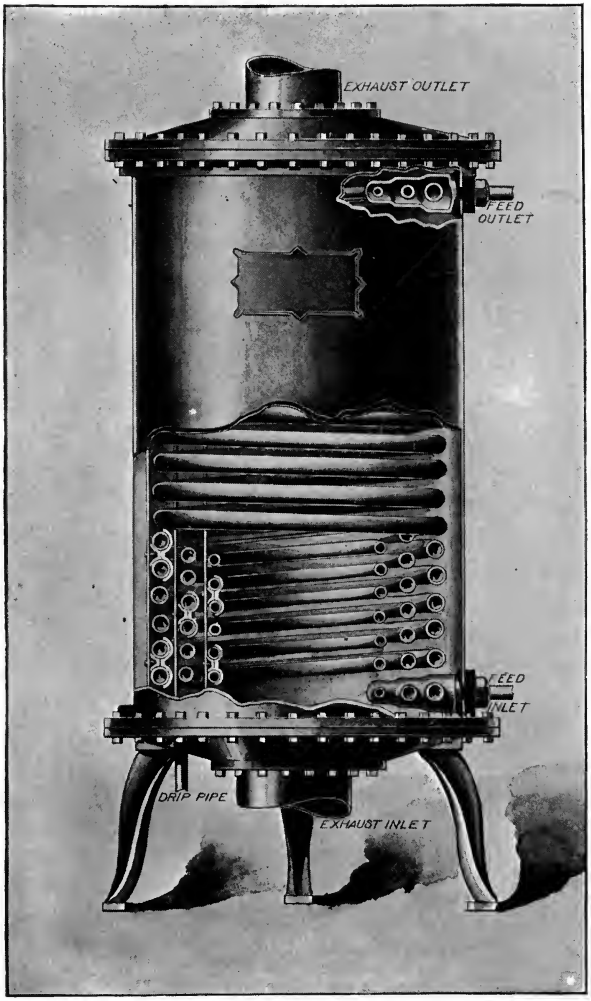


FIG. 39.—Pipe-coil Heater by Harrisburg Pipe Bending Co.

In the Harrisburg heaters, Fig. 39, the connection of water-pipe to coils is accomplished by using a special fitting, to which the coils of three or less pipes are connected top and bottom inside the

shell, and by means of flanges and threaded ends outside the shell.

Another type of closed-pressure heater is the "Multo-Current" feed-water heater, designed by the Blake and Knowles Steam Pump Co. In this heater the ends of the tubes are firmly expanded and secured in the two heads, one of which is rigid and part of the main-shell casting. The other head is bolted to a steel plate or diaphragm, the periphery of which is attached to the flange of the heater-shell. This arrangement takes care of the unequal expansion between the tubes and the shell under all conditions of temperature and pressure.

The tubes are arranged in six nests and the flow of water through them is controlled by partitions in the water-chambers at each end of the heater, so that the water will pass through each nest in turn, thus traversing the heater six times. The circulation is positive and the heater is designed to give an even distribution of water. The exhaust-steam is thoroughly and evenly distributed by means of partitions in the heater-shell and the flow is so diverted as to pass three times through the heater and circulate freely among the tubes. The absence of stuffing boxes and packings of any kind in this heater does away entirely with the possibility of leakage and loss of feed-water. The cross-sectional area between the tubes is greater than the area of the exhaust pipe, offering no obstruction to the flow of the steam and eliminating back pressure.

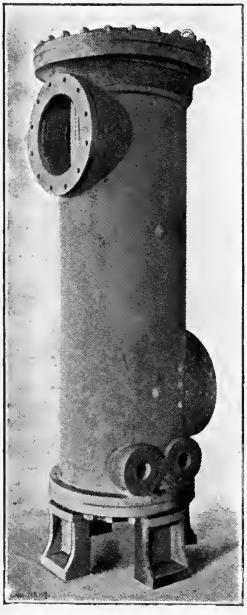


FIG. 39*a*.— Vertical Multi-current Feed-water Heater of 800 Horse-power.—(Designed and built by the Blake-Knowles Steam-pump Works, New York.)

Access to the heater is had by removing the heads; the tubes of the vertical heaters can be cleaned from the top and the horizontal heaters from either end. Mud-blows are provided to keep the heater clean and free from sediment. Every heater is tested under 250 pounds pressure per square inch, giving a safe working pressure of 175 pounds.

The makers say that the number of British thermal units passing through a square foot of thin copper per hour, with a difference of 1° F., between the warmer and colder mediums, is in the case of a high-pressure steam feed-water heater or evaporator, 400 units when the steam and water move at the appropriate speed, but only 200 to 240 units when the steam and water remain quiet during the heating process. In low-pressure steam apparatus-like condensers, feed-water heaters and vacuum evaporators, the figures are 360 units when the steam and water move at the right speeds and 120 units when the steam and water are quiet. In apparatus heated by hot water, such as sterilizers, 200 B.T.U. are transmitted per hour when the water is moved in the correct manner and 40 to 60 B.T.U. when the water remains quiet.

The following results were obtained in a test of one of these heaters of the vertical pattern rated at 125 horse-power.

Exhaust openings, inches diameter	8
Feed openings, inches diameter	1½
Exposed tube surface, square feet	24.05
Total quantity of feed-water passed through heater per hour, pounds	6857
Initial temperature of feed-water at entrance, ° F.	55
Temperature of feed after passing through first nest of tubes, ° F	118
Temperature of feed after passing through second nest of tubes, ° F	155
Temperature of feed after passing through third nest of tubes, ° F	170
Temperature of feed after passing through fourth nest of tubes, ° F	190
Temperature of feed after passing through fifth nest of tubes, ° F	195.8
Final temperature of feed after passing through sixth nest, ° F	203
Rise in temperature of feed-water, ° F	148
Temperature of steam leaving the heater	206
Heat absorbed by the feed-water per hour, B.T.U.	1,014,836
Heat absorbed per square foot of tube surface per hour, B.T.U.	42,186
Velocity of water through tubes per minute, ft.	125

On the basis of the ordinary commercial rating of 1 horse-power capacity per every 30 pounds feed-water heated, this test

shows that a heater containing 24.05 square feet of the tube surface is capable of handling 228 horse-power. This would reduce to 9.5 horse-power per square foot of tube surface which is over three times better than the commercial rating of 3 horse-power per square foot.

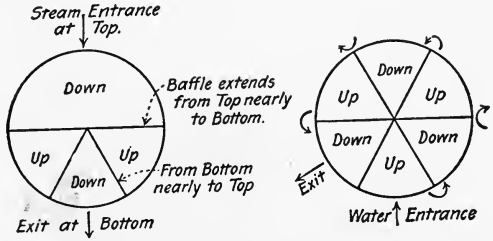


FIG. 39*b*.—Baffle Plates in Steam-space. Partitions in Heads Connected to Water-tubes.

Diagrams illustrating Flow of Fluids in Feed-water Heater.

The B.T.U.'s per degree difference of temperature of entering water and heated water for this case are 816, occupying on Mr. H. L. Hepburn's diagram a position midway between the corrugated and the plain-tube heater.

It should be kept in mind that the water travels six times the length of the heater, while in some pressure heaters never more than twice the length.

We now come to a more useful type of heater, as far as the completeness of throwing down scale-forming substances from the water is concerned—the open heater and purifier.

In this class we have the Cochrane heater, which consists of a cast-iron box, made in sections, bolted together at the flanges.

The upper parts, as shown by Fig. 40 and Fig. 41, contain trays with serrated edges to break up the water as it passes down through or over them.

These trays are all set in the path of the incoming exhaust-steam, are inclined in opposite directions, and also vary in number and size as is required by the work to be done by the heater and the character of the water fed to the heater. The trays are readily removed through the doors provided for the purpose, and are likewise prevented by guides from rattling, apt to be caused by the pulsations of the entering exhaust-steam. The cold water

entering the heater is regulated in amount by means of a balance valve operated by a copper-ball float in the lower part of the heater. Just above the water level is a skimmer, which is also an overflow, draining to a trap. Below this outlet there is a filter-bed of coke. The outflow of the feed-water is through this coke and under a shield which keeps the coke away from the outlet.

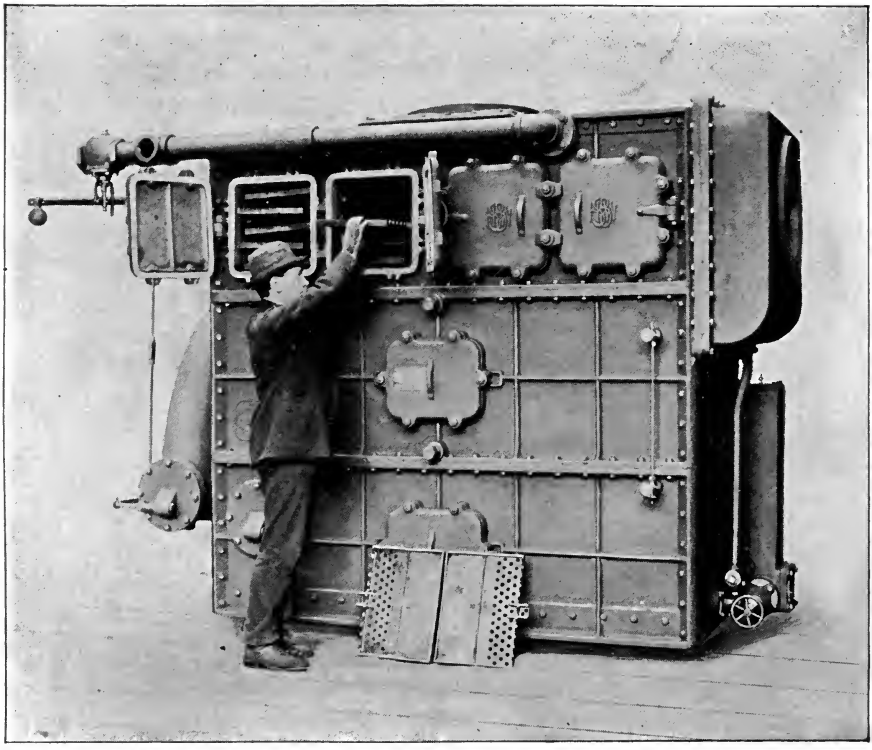


Fig 40.—A Cochrane Heater.

The heater is also fitted with an oil-separator, gauge-glass, blow-off, and all fittings necessary to make it a complete heater and purifier. It is installed with the exhaust issuing from the top of the heater or a vent out of the top, and drawing the exhaust-steam through the regular side inlet, wasting what is not required for heating. This method is used where there is a surplus of exhaust-steam.

The Webster "vacuum" heater, Fig. 42, is one of the so-called open heaters; it is however sealed from the atmosphere, so that in case the exhaust-steam from the engine decreases from its usual quantity the heater will draw from the exhaust pipe all that is possible to obtain in that way, and should the steam be less than is required to produce a certain temperature in the feed-water, a partial vacuum will result and the heater for a time becomes a sort of condenser.

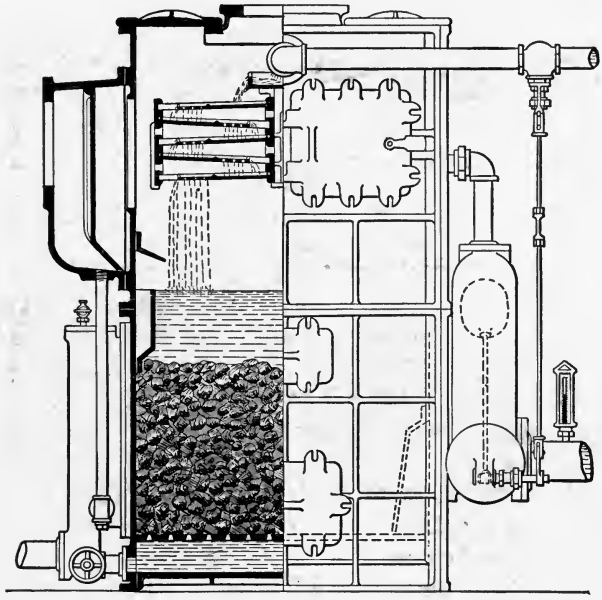
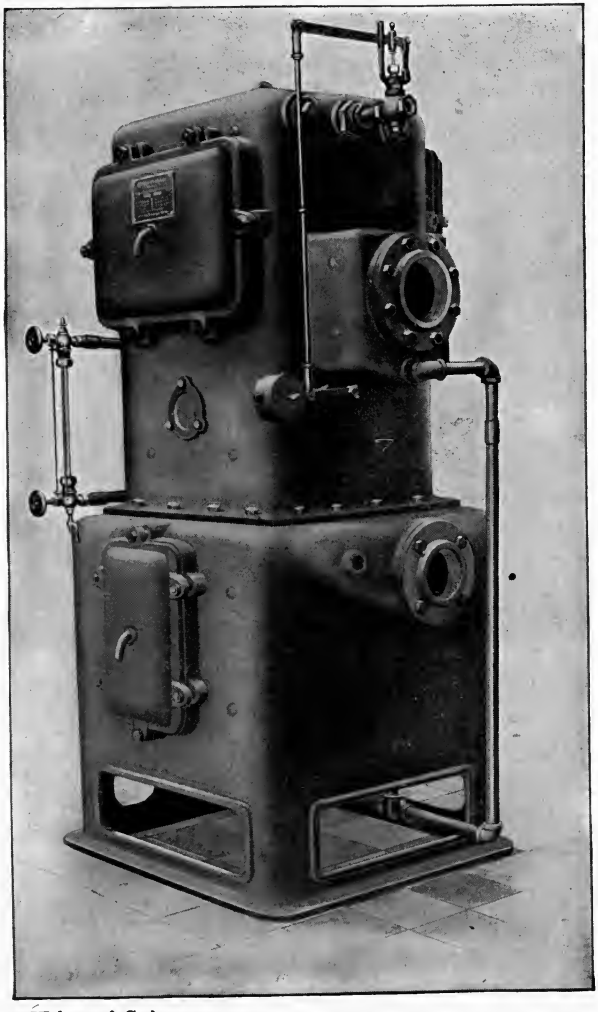


FIG. 41.—Half-section, Half-elevation Cochrane Heater.

The standard heater and purifier of this make has a cast-iron shell exhaust inlet near the top and fitted with a weighted safety-valve. The exhaust-steam is directed over a series of inclined copper trays, where it meets the water which is allowed to trickle over and down from one tray to the next. The water then falls to the settling-chamber at the highest temperature and from that chamber it is pumped to the bo lers. An apron across the entire settling-chamber in front of the submerged outlet prevents scum or other light impurities from passing to the boiler. The heater

may also be provided with a filtering compartment where conditions require it.



(Warren Webster & Co.)

FIG. 42.—Feed-water Heater, Purifier, and Filter.

In the Victor Manufacturing Company's cast-iron feed-water heater and purifier, Fig. 43, the water enters a balanced valve on top of the heater and runs into a circular water-box, the upper

edge of which is surrated, from which it runs into the pans underneath in very thin sheets if properly regulated; each alternate pan has a hole in its center.

The steam enters the side of the heater and circulates about the pans and passes out of the top of the heater. After leaving the pans the water passes down through a pipe to a settling-chamber, where sediment, etc., can be blown off. The water

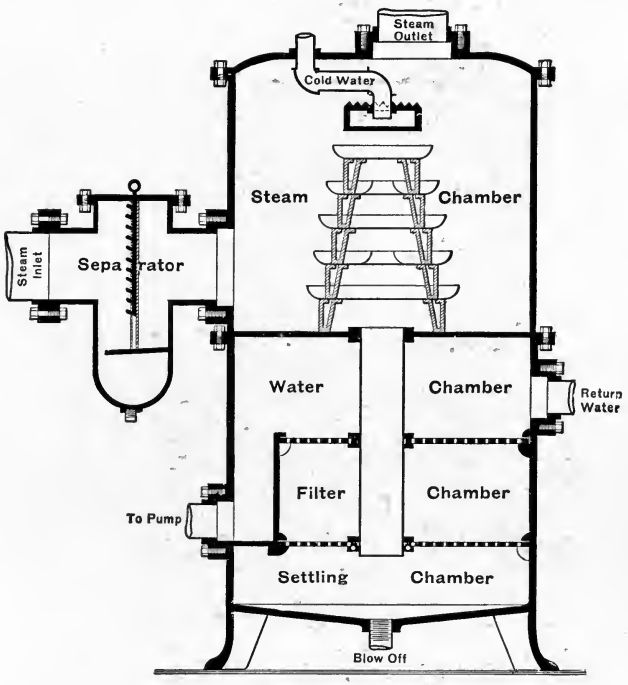


FIG. 43.—Vertical Section of Victor Heater.

filters upward through the filter-bed and flows to a suction pipe. The filter perforated plates can be easily removed. The incoming water is regulated by means of a copper-ball float connected to the inlet valve.

The Hoppes live steam purifier, Fig. 44, consists of a cylindrical shell, in which are arranged horizontal pans, one over the other, so as to be readily removed. These pans receive the feed-water, and through contact of the steam with the water the heavier

solids settle, while carbonates, sulphates, silica, and other scale-forming substances adhere to the under sides. The elastic feature of the trays enables them to be twisted and distorted and the hard substance can be easily removed from them.

The Hoppes heater, though similar to the purifier in so far as the form of the pans is concerned, consists of a steel cylinder, cast-iron heads easily opened for cleaning the trays. The exhaust-steam after passing through an oil-separator enters the heater at the rear

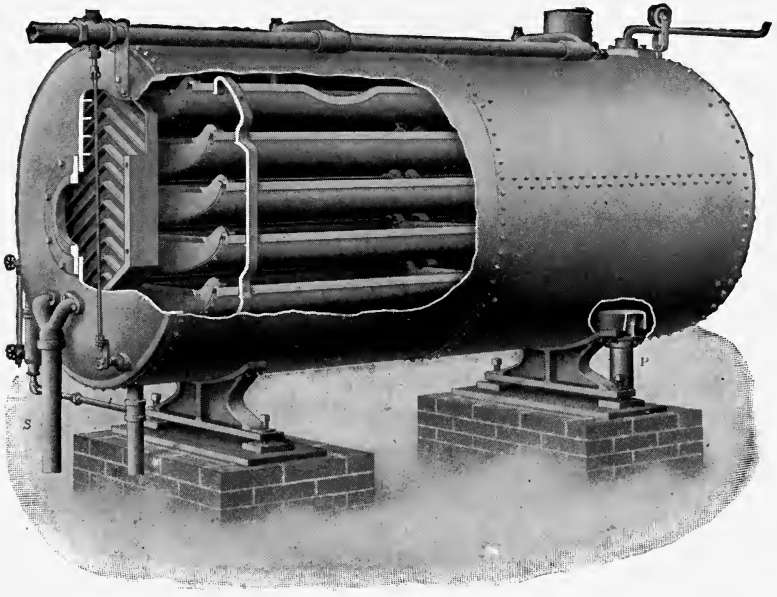


FIG. 44 —Heater Made by the Hoppes Mfg. Co.

end and leaves the shell at the front, that is such portion of it as has not been condensed.

The Stillwell heater and purifier, Fig. 45, is similar in operation to other open heaters. It is built with a riveted-steel shell, and is equipped with flat strainers, located midway of its height, with a filtering chamber at the bottom.

Steam is admitted to a cast-iron hood-piece opposite the trays in the bottom of which the entrained oil is collected and from which it is discharged. The steam then passes up through the

filter compartment, then over a partition to a pure-water pocket, and then out at the bottom. The rating of an open heater is a matter in which little has been recorded.

A common rule for a pressure or closed-tube heater is to allow $\frac{1}{3}$ square foot of heating-surface for one boiler horse-power, water

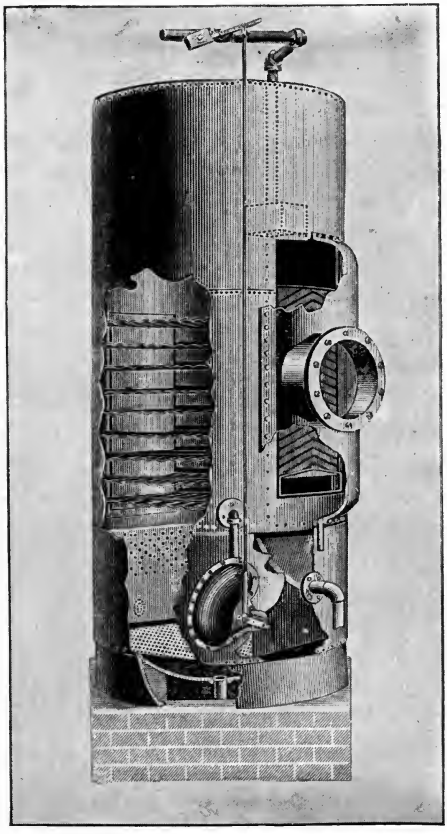


FIG. 45.—The Stillwell Combined Heater and Filter.

heated to 210°–212° F. In designing a heater, however, the heating-surface should be made large enough or ample to transmit the maximum number of heat-units per unit of time, and then the water velocity should be adjusted to suit the required capacity.

One heater manufacturer bases his sizes on 350 B.T.U. as the maximum transmitted, while for some types we should take

not more than 150 to 200 B.T.U. as the maximum. For open heaters the capacity is limited only by the amount of steam and water that can be brought together in a unit of time and thoroughly mixed and is necessarily determined by the experience of the maker with the results obtained by his machine in many localities.

From a large experience with feed-water heaters, Mr. J. M. Duncan has given this information:

ANALYSES OF WATERS.

(Grains per Gallon.)

	Artesian Well. A.	Ponds and Springs. B.	To Boiler. C.	City Water. D.	Artesian Well. E.
Carbonate of lime	2.90	8.81	3.75	8.56	9.44
" " magnesia	9.40	6.49	2.58		
Sulphate of lime	11.65	0.83	0.58	18.42	6.46
Sodium chloride	76.40	.....	.....	65.52	5.27
Alumina	0.52				
Iron oxide	.....	.....	.....	.....	0.93
Organic matter	Trace	.....	.....	22.23	5.10
Totals	100.87	16.13	6.91	114.73	27.20

A. N. Y. & Queens Co. R.R. Co. Power Station, Astoria, L. I.

B. Union Car Co., Depew, N. Y.

C. Same after passing through open heater, where 10 lbs. soda-ash were added to water per day.

Boiler plant, 1000 H.P. Root boilers.

Deposit, 1 to 1½ bbls. of soft sludge removed every two weeks.

D and E. Astoria, L. I., Silk-mills.

D. Requires 1 lb. trisodium phosphate for each 50 boiler H.P. per day.

Fuel Economizers.—Another form of feed-water heaters obtains the heat from the flue-gases after they leave the boiler or furnace on their way to the chimney or other outlet. They are in reality sectional feed-water heaters, consisting of a great number of cast-iron pipes or tubes about 4 inches in diameter by 9 or 10 feet long, set in rows and connected together by the necessary headers. The water is pumped into them at the end farthest from the boiler up-take and taken out where the gases are the hottest. Each tube is provided with a geared scraper which is moved

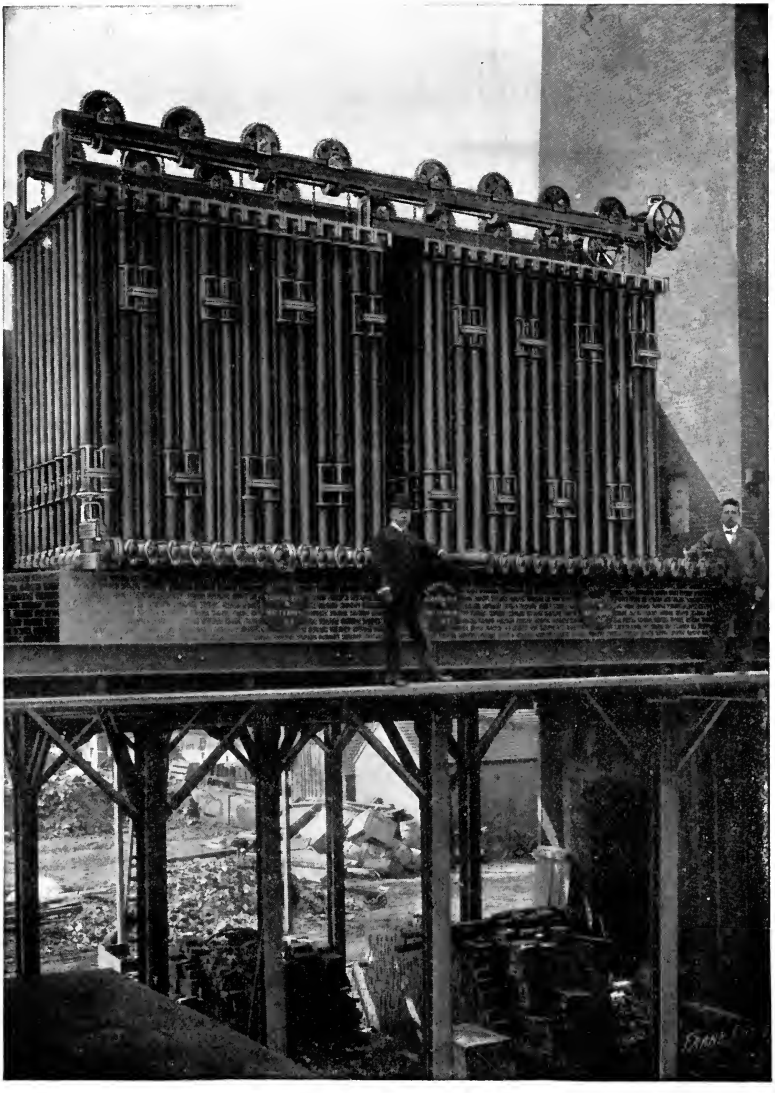


FIG. 46.—Green Fuel Economizer.

up and down the outside of the pipe, removing all soot as fast as it accumulates. A small amount of power from engine or motor does this work.

The tubes are tested to a pressure of 500 pounds per square inch; the water in them when in use is at boiler pressure.

The whole apparatus should be encased in a brick wall or other non-conducting covering. The pipes should be blown-off once each day, as otherwise the scale will accumulate in them, and they should have more care than ordinary feed-water heaters.

Fig. 46 shows a Green fuel economizer. Economizers materially add to the efficiency of many steam-plants. These figures are from one actual case:

Boiler horse-power	1200
Heating-surface in economizer	6400 sq. ft.
Flue area for economizer	6400 sq. in.
Economizer tube surface per boiler H.P.	5.33 sq. ft.
Cost, erected, per square foot of economizer surface	80 cents
Cost, erected, per H.P. of boilers	$4 to $6

The draft in a chimney is reduced by passing the gases through an economizer, for the temperature is reduced from 400°–500° F. to 265°–300° F., or even lower.

Water is heated in the economizer to a much higher degree than in a steam-heater, depending on the temperature of the escaping gases as to its higher limit.

Carbonate of lime, and in some cases chloride of magnesium and calcium sulphate, are removed from the water passing through economizers.

CHAPTER IX.

WATER-SOFTENING.

SOFTENED water is water which has been freed from the salts of lime and magnesia, iron, and aluminium. It cannot produce scale nor corrosion. Dr. Clark, chemist, invented the first softening process about sixty years ago in England, treating water with lime to remove the carbonic acid and lime and magnesia carbonates. Then came Dr. Porter's process of using soda-ash to remove the sulphates of calcium and magnesia. Following this has come the Porter-Clark process, which is a combination of the two just mentioned.

The use of alum for purification dates to early times in China and India.

Water can be softened down to 3 to 4 grains of scale-forming ingredients per gallon, but if the quantity is reduced to 5 to 7 grains it will give satisfactory results.

Chemistry of Softening Water.—Softening of water is accomplished by chemical precipitation. To remove carbonates lime is used. On adding lime the carbonic acid unites with it, resulting in the formation of calcium carbonate. This is the reaction:

$$CaCO_3 + CO_2 + Ca(OH)_2 = CaCO_3 + H_2O.$$

Being but slightly soluble, it is precipitated.

The reaction for carbonate of magnesia is something like this:

$$MgCO_3 + CO_2 + Ca(OH)_2 = MgCO_3 + CaCO_3 + H_2O;$$

but magnesium carbonate being quite soluble, a further quantity of lime must be added:

$$MgCO_3 + Ca(OH)_2 = Mg(OH)_2 + CaCO_3;$$

then the hydrate is precipitated.

Sulphates are removed by the use of sodium carbonate; lime is required for magnesium sulphate:

$$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4$$

and

$$MgSO_4 + Ca(OH)_2 + Na_2CO_3 = Mg(OH)_2 + CaCO_3 + Na_2SO_4.$$

Sodium sulphate is quite soluble and an unobjectionable substance in quantity usually found in water. Chlorides and nitrates may be removed in a manner similar to the sulphates.

Carbonate Waters.—Where carbonate of lime alone is present, for each grain per gallon of carbonate of lime found in the water 4 ounces of pure caustic lime per 1000 gallons of water will be required to precipitate the lime as carbonate.

Sulphate Waters.—Where there is only the sulphate of lime present, for every grain of sulphate of lime per gallon found in the water, $1\frac{3}{4}$ ounces of pure carbonate of soda (soda-ash) are required per 1000 gallons of water treated.

Carbonate and Sulphate Waters.—The carbonate and sulphate of lime both being present, as is the case in some waters, caustic soda alone is all that is needed to precipitate both of the salts.

For water containing 6 grains of the carbonate per gallon of water, use 9 ounces of pure caustic soda per 1000 gallons of water to be treated, which quantity should also eliminate 8.16 grains of the sulphate. A water containing 14.16 grains of the two kinds of salts per gallon, of which 6 grains were carbonate and 8.16 sulphate, would be treated by adding caustic soda as above.

The cost of any process or method of treatment depends to a great extent upon the chemistry of the water to be treated, of which the following tables * will give some idea.

One pound of "carbonate of lime" requires for its precipitation:

	.56 lb.	of lime at $\frac{1}{4}$ cent per pound.....	$0.0014
or	.80 "	" caustic soda at 2 cents per pound...	.0160
or	3.15 lbs.	" barium hydrate at $2\frac{1}{2}$ cents per lb...	.0787
or	2.18 "	" sodium phosphate at 4 cents per pound.....	.0872
or	11.92 "	" tannin extract, 27%, at $2\frac{3}{4}$ cents per pound.....	.3278
or	2.28 "	" sugar at 5 cents per pound.....	.1140

* Kennicott Water-softener Co.

One pound of "sulphate of lime" requires for its precipitation:

	.85 lb.	of soda-ash at 1 cent per pound	$0.0085
or	1.94 lbs.	" sal-soda at .65 cent per pound	.0126
or	1.53 "	" barium chloride at 2 cents per lb.	.0306
or	1.60 "	" sodium phosphate at 4 cents per pound	.0640
or	8.76 "	" tannin extract, 27%, at 2¾ cents. per pound	.2409
or	1.68 "	" sugar at 5 cents per pound	.0840

And such other reagents as may be found necessary.

The method of softening as employed by the Industrial Water Co. is that in use on the Pennsylvania Lines west of Pittsburgh, Northwest System, at Middlepoint, Ohio, where a machine of capacity to soften 10,000 gallons of water an hour is in use.* The water to be treated is a particularly bad one, yet the softening and purification are practically complete, as will be seen from the following analysis (grains per U. S. gallon).

	Raw Water.	Treated Water.
Calcium carbonate, $CaCO_3$	16.50	2.14
" sulphate, $CaSO_4$	16.08	
Magnesium carbonate, $MgCO_3$	.....	1.32
" sulphate, $MgSO_4$	19.65	
" chloride, $MgCl_2$	1.61	
Sodium carbonate, Na_2CO_3	.....	0.21
" sulphate, Na_2SO_4	3.76	43.81
" chloride, NaCl	.....	2.64
Silica, SiO_2	0.65	0.58
Oxides of iron and aluminium, Fe_2O_3, Al_2O_3	0.19	0.19
Volatile and organic matter	7.46	1.23
Total solids	63.52	51.61
Scale-forming solids	54.68	4.23

Besides the impurities shown in this analysis, the raw water is impregnated with sulphureted hydrogen, which renders it especially corrosive to the brass fittings.

The chemicals used are fresh lime and soda-ash, and this particular water requires for treatment approximately 4.75 pounds of lime and 4.5 pounds of soda per thousand gallons. Running at full capacity, 1744 pounds of incrusting calcium and magnesium salts are removed per day.

* *Railroad Gazette*, 1903.

Referring to the sectional view, the water enters the inlet *I* and passes to the overshot water-wheel *W*, which furnishes the

FIG. 47.—Water-softening Plant, Middlepoint, Ohio—Pennsylvania Lines West of Pittsburgh.

power to drive the stirring-devices. Once in twenty-four hours lime is slaked in the box *lb* and dropped through the pipe *lp* to the bottom of the lime-tank *L*, where it is kept in suspension as

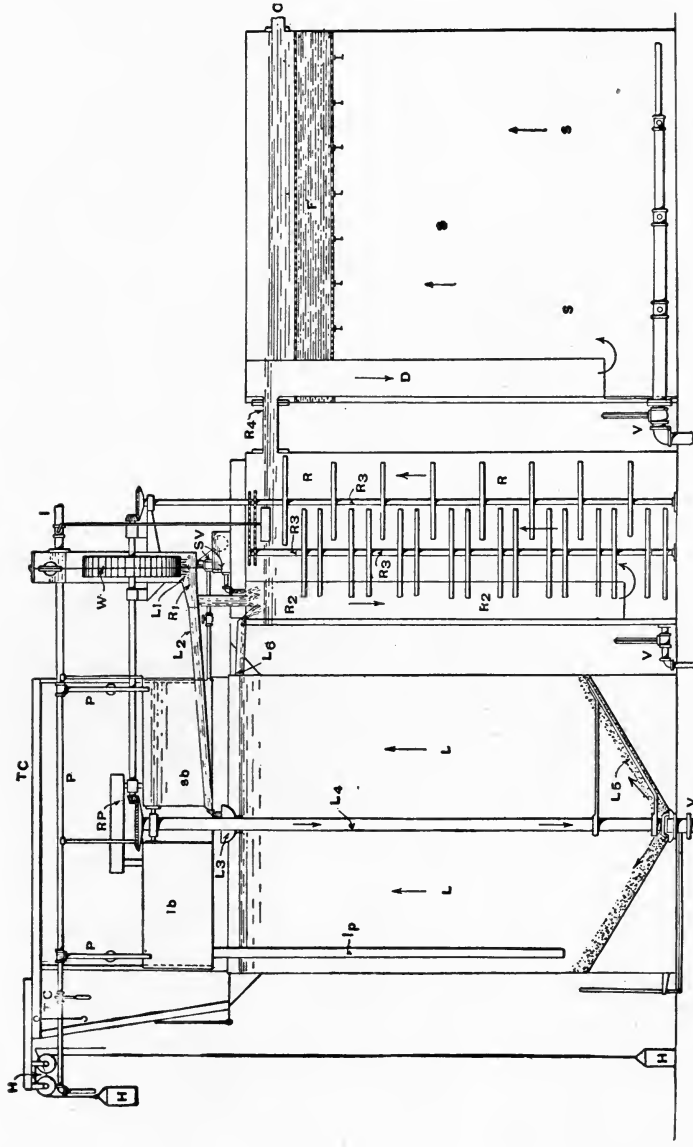


FIG. 48.—Water-softening Plant at Middlepoint, Ohio—Pennsylvania Lines, West.

milk of lime by the rotation of the agitator *L*5. Through the gate *L*1, in the bottom of the water-wheel box, a definite proportion of raw water flows by the chute *L*2 and the bowl *L*3 down the pipe *L*4 and ascends through the suspended milk of lime. In its slow upward progress it dissolves a sufficiency of calcium hydroxide and becomes saturated lime-water. Owing to the absence of agitators in the upper portion of this tank, the liquid there is comparatively quiet, and by the time the exit *L*6 is reached, all the heavy particles of milk of lime have been left behind by the lime-water, which issues clear and is of constant strength. Flowing through the chute *L*6 it meets the main body of raw water from the gate *R*1 as well as the proper proportion of soda-ash solution which has previously been prepared in the box *sb*. The soda solution is fed by means of the valve *SV*, which is so constructed and automatically operated that the flow of solution is always proportional to the amount of water to be treated. The water and the reagents then pass downward through the reaction-pipe *R*2 into the reaction-tank *R*. This tank is of such a size as to permit the water to remain in it for a period of half an hour, during which time it is very thoroughly agitated by means of the stirrer-bars on three vertical shafts, *R*3, *R*3, *R*3, actuated from the water-wheel by beveled gearing and chain transmission. When it is ready to pass out at *R*4 and through the downtake *D* into the settling-tank *S*, all the reactions are completed and the precipitate is in such condition that it will settle very readily. The precipitate subsides to the bottom of the settling-tank *S*; the treated water rises slowly and passes through the wood-fiber filter *F*, where the very small quantity of matter which is carried in suspension is deposited. The water then flows clear and soft from the outlet *O* to the storage-tank. At intervals the precipitates which have settled to the bottom of the tanks are disposed of by opening the valves *V*, *V*, *V*. In washing the filter and disposing of the precipitates, approximately 3 per cent of the total amount of water treated daily is used. When required, water is supplied to the lime-box *lb* and the soda-box *sb* through the piping *P*. This also supplies water for operating the brake-controlled chemical hoist *H*, which has capacity to raise 200 pounds of reagents in 10 seconds. By means of the trolley crane *TC* and the receiving platform *RP* the chemicals are conveniently distributed to their respective boxes.

Another plant installed by the same company, whose system is one of continuous operation, combined with automatic regulation of the supply of chemicals, is at Ivorydale, Ohio, at the works of the Proctor & Gamble Co., with a capacity of 35,000 gallons per hour. It purifies all the water used for feed purposes in their boiler-house, which supplies the steam used in the manufacture of

FIG. 49.—Water-softening Plant of Proctor and Gamble Co., Ivorydale, Ohio.

soap and candles, as well as that required in the refining of cotton-seed-oil and glycerin. In addition, softened water is also supplied to the boilers of the company's electric-lighting plant, and also to the locomotives of the Ivorydale & Millcreek Valley R.R.

The plant installed is shown by the view, Fig. 49, and by the plan and sections, Figs. 50 and 51. It consists of a lime-tank, a reaction-tank and two settling-tanks, with a wood-fiber filter at

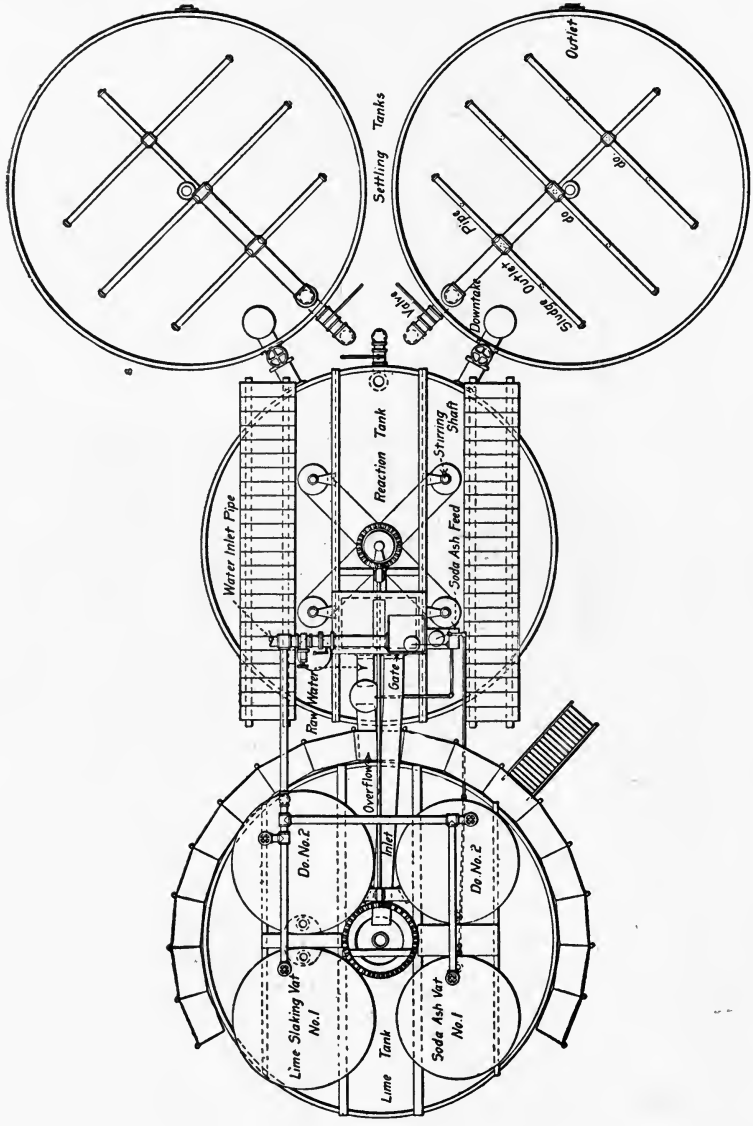


FIG. 50.—Plan of Water-softening Plant, Proctor and Gamble Co., Ivorydale, O.

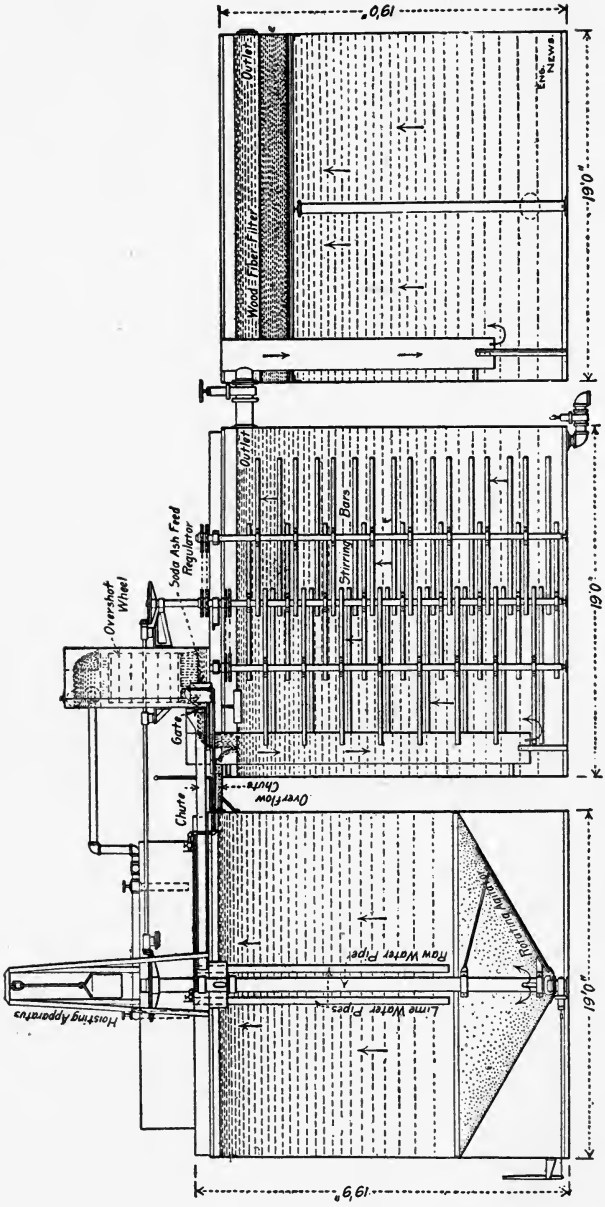


FIG. 51.—Sections of Water-softening Plant, Proctor and Gamble Co., Ivorydale, O.

the top of each settling-tank through which the water passes in its upward flow. In addition there are two small vats for slaking lime and two similar ones for preparing soda-ash solution, all supported on the lime-tank.

The untreated water first passes to the overshot wheel, located over the reaction-tank, as shown in Figs. 50 and 51. After serving its purpose here, by driving agitators in the reaction-tank, the water is divided into two parts: The main part goes into the reaction-tank and a definite portion flows to the bottom of the lime-tank through a central inlet pipe. Milk of lime is prepared once in twelve hours in the lime-slaking vats, and admitted to the bottom of the lime-tank, where the lime is kept in suspension by the rotating agitator shown in Figs. 50 and 51. In its slow upward progress through the milk of lime the untreated water dissolves a sufficiency of calcium hydroxide and becomes saturated lime-water. Owing to the absence of agitators in the upper portion of this tank the liquid there is comparatively quiet, and by the time the exit is reached all the heavy particles of milk of lime have been left behind by the lime-water, which issues clear and of constant strength. Flowing through the chute it meets the main body of raw water issuing from the gate in the bottom of the wheel-box, as well as the proper proportion of soda-ash solution which has previously been prepared in the soda-vats.

The plant was designed to have ample capacity to ensure: (1) The use of nothing but clear saturated lime-water; (2) Complete reaction of the chemicals; (3) Thorough settling, with an upward rise of water at so slow a rate that almost none of the precipitate reaches the wood-fiber filter; thus rendering it unnecessary to renew the wood fiber except at very long intervals.

An analysis of water before and after treatment, by Froehling & Robertson, of Richmond, Va., is given on the next page.

This particular water requires for treatment approximately 4 pounds of fresh lime and 0.5 pound soda ash per 1000 gallons. When running at full capacity 2006 pounds per day of incrusting calcium and magnesium salts are removed by this plant.

The soda solution is fed by means of a valve and connections which are so constructed and automatically operated that the flow of solution is always proportional to the amount of water to

	Grains per U. S. Gal.	
	Raw Water.	Treated Water.
Silica	0.7523	0.2099
Alumina and iron oxide	.0641	.0641
Calcium carbonate	13.3140	.7990
" sulphate	.1750	.5190
Magnesium sulphate	3.0384	1.2072
" carbonate	3.1142	.3966
Sodium chloride	1.2772	1.3297
" sulphate	.4141	1.7962
Total	22.1493	6.3217

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be treated. The water and the reagents then pass downward through a pipe into the reaction-tank. This tank is of such size as to permit the water to remain in it for a period of one hour, during which time it is thoroughly agitated by means of the stirrer bars on five vertical shafts, actuated from the water-wheel by beveled gearing and chain transmission. When the water is ready to pass to and through the downtakes into the settling-tanks, all the reactions are completed and the precipitate is in such condition that it will settle very readily. The precipitate subsides to the bottom of the settling-tanks; the treated water rises slowly and passes through the wood-fiber filters, where the very small quantity of matter which is carried in suspension is deposited. The water then flows clear and soft from the outlets to the various boiler houses.

At intervals the precipitates which have settled to the bottom of the settling-tanks are disposed of by opening the valves connected with the sludge piping, located at the bottom of the settling-tanks.

In washing the filter and disposing of the precipitates, approximately 2 per cent of the total amount of water treated daily is used

Hoisting apparatus is provided to raise the various reagents from the ground level to the lime- and the soda-mixing vats.

Mr. E. J. Yard, chief engineer of the Denver & Rio Grande, says: We have three purifying plants in use on this system. Two were put in by the Industrial Company—one at Ruby and one at Helper, and one by the Tweeddale Company at Thompson's

Springs. The estimated cost of chemicals per 1000 gallons at Ruby and Helper is approximately 1 cent; the cost for operating the plant, including labor and chemicals, averages about 4 cents. The cost of the chemicals per 1000 gallons of water treated at Thompson's by the Tweeddale system is 7.6 cents; labor, fuel and incidentals bring up the total cost of treatment to 11½ cents.

The Pennsylvania Lines West of Pittsburgh report two plants, put in by the Industrial Company at Washington and Middlepoint, Ohio, respectively, and in service since June.

The figures for Washington are: Total cost per 1000 gallons 2.238 cents; average scale-forming material in raw water, 29.04; average degree of hardness of treated water, 4.97. For Middlepoint: Total cost per 1000 gallons 6.052 cents; average scale-forming material in raw water, 54.17; average degree of hardness of treated water, 5.98.

The Chicago and Northwestern Railway furnishes some figures on the cost of operating 16 purifying plants on the North Western during July, 1903, giving the cost of pumping water without softening, and the cost of softening. The former ranges from 1.59 to 8.17 cents per 1000 gallons, and the latter from 0.73 to 6.33 cents per 1000 gallons, for the different stations. The cost of chemicals ranged from 0.47 to 6.94 cents per 1000 gallons.

Figs. 52, 53, and 54 illustrate the Kennicott water-softener. It consists of a tall cylindrical tank with a platform at its top, on which is located the apparatus for dissolving the reagents and automatically varying their inlet to the raw water.

In the center of the tank is a conical downtake, within which is the lime-water saturator; the mixing-tank for this is in its top.

After reagents and raw water are thoroughly mixed, the scale-forming substances are deposited at the bottom, from which they are blown off or run off to sewer. After the water comes down the central tube it rises through the perforated baffle plates, upon which plates any remaining precipitate is gathered, after which it falls off to bottom. These plates never have to be cleaned. At the top the water finally passes through a wood-fiber filter, where any precipitate which has gotten through the baffle plates is taken up; the water then passes through the overflow outlet to the proper supply lines.

The power for mixing reagents and water is supplied by the

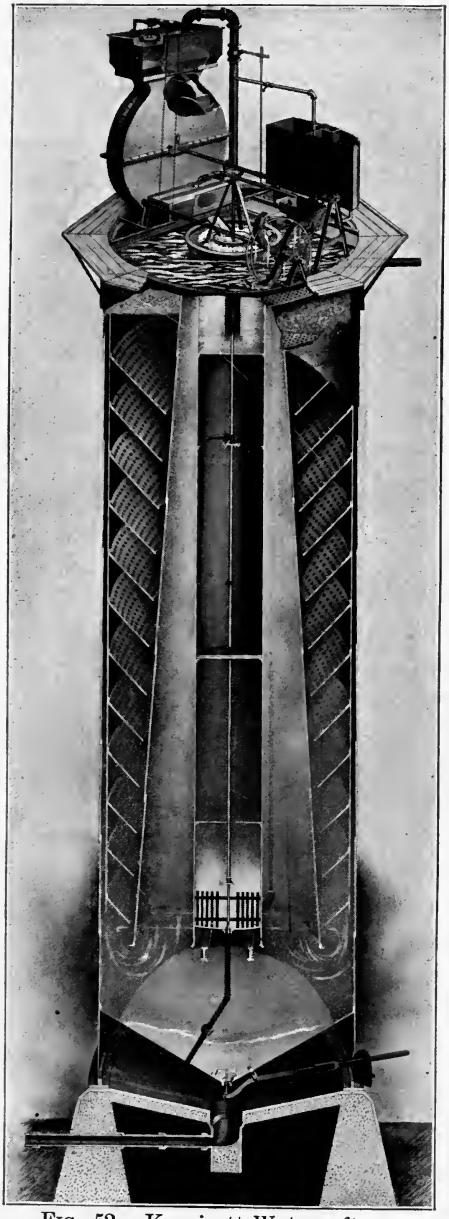


FIG. 52.—Kennicott Water-softener.

water passing over a water-wheel in a casing, shown in the illustration. The lime and soda-ash are lifted by the same power; a drum on the water-wheel shaft, loose fit, is engaged by a clutch and operates a rope, also shown in the illustration.

The water flows from the "hard-water box," top of Fig. 54, into the softener over the encased water-wheel; one or more of the reagent boxes like the one shown at the bottom of Fig. 54 are provided as needed.

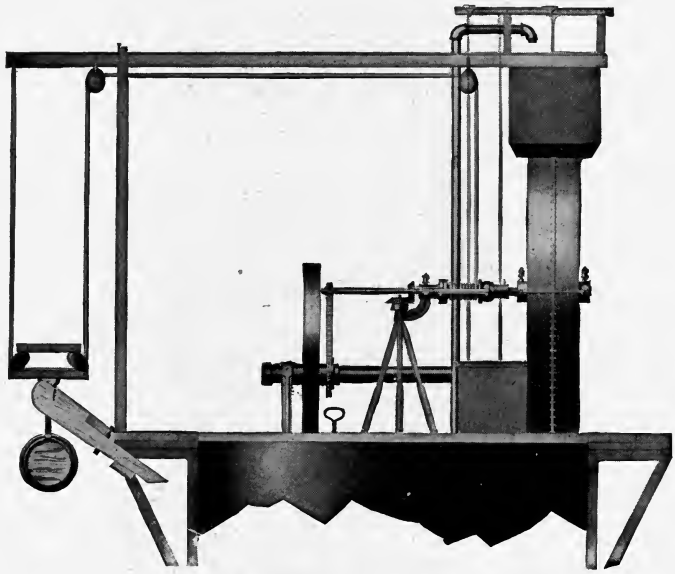


FIG. 53.—Kennicott Automatic Hoisting Apparatus.

As the amount of the water pumped into the softener varies the head of water in hard-water box it raises or lowers the float in it. This float is connected to the lift-pipe, so that the head of the reagent over the opening in the lift-pipe is at all times the same as the head of hard water over opening in hard-water box.

The Union Pacific Railroad has eleven Kennicott softeners, varying in capacity from 8000 to 20,000 gallons per hour. Twenty-five more are now under erection at the rate of three per month. The cost of chemicals varies from 0.3 to 3.6 cents per 1000 gallons. The ten plants now in operation treat 1,441,000 gallons per day at an average cost of $1\frac{1}{8}$ cent sper 1000 gallons. The chief engineer

says: "The saving in boiler repairs certainly warrants the expenditure of the amount necessary to treat the waters at all points where we either have, or are erecting, softeners. Another saving is in locomotive fuel, which will be no small item. . . . In the ten plants we are removing 2790 pounds of solids per day. Cost of chemicals for this work is 58¼ cents per 100 pounds of incrusting

FIG. 54.—Kennicott Automatic-regulating Device.

solids removed. Even though this figure were doubled it would still be an economy, as any experienced man knows that 100 pounds of scale cannot be removed from boilers for any such figure."

The Chicago, St. Paul, Minneapolis & Omaha has four Helwig and one Kennicott softener. The average cost for chemicals per 1000 gallons is given at 3 cents.

FIG. 55.—Kennicott Water-softener, Union Pacific R R., Columbus, Neb.

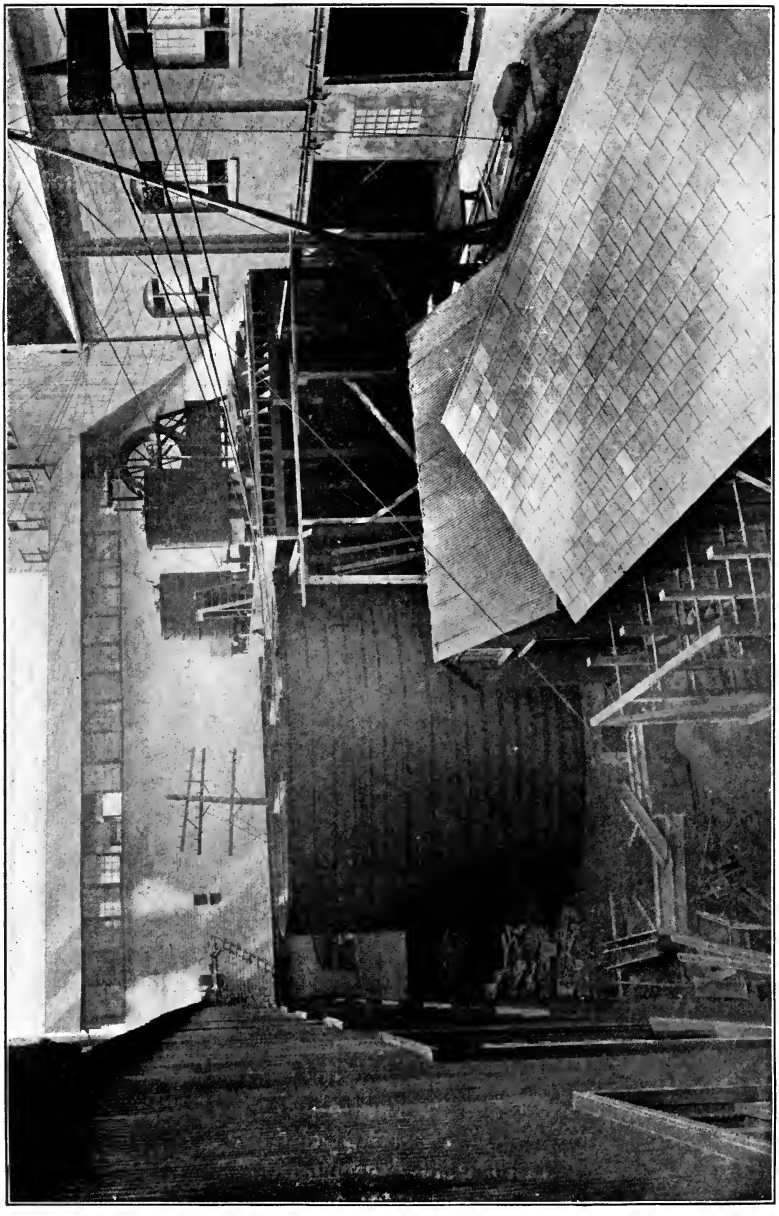
In general, it may be stated that there are two systems of water softening, the intermittent and the automatic apparatus; the one now about to be described and the two preceding belong to the latter classification, the remainder to the intermittent type.

The N. Y. Continental Jewell Filtration Company's scientific-automatic water-softening apparatus is so called because the raw water flows into the apparatus in a continuous stream at the point of the inlet, the purified water likewise flowing continuously from the point of outlet. The apparatus comprises one main settling-tank, smaller auxiliary tanks for chemical solutions, mixing, etc. The water enters the inlet or controlling-tank through a valve at the top, and is automatically controlled by a system of floats. It then flows over a water-wheel, furnishing power for the mixing devices, thence to a lower vessel in which the flow is divided by means of an adjustable gate; the larger portion goes to mixing-tank, the balance to solution-tank where it dissolves the reagent, the solution being carried to mixing-tank, encountering the steam of raw water. Here it is thoroughly mixed by a continuously revolving mechanical agitator. From here it passes to the bottom of a large settling-tank, where it slowly rises to the top, the heavier particles settling. In the top of the tank is a bed of filtering material, intercepting the lighter particles and allowing the softened water to flow from the top outlet bright and clear.

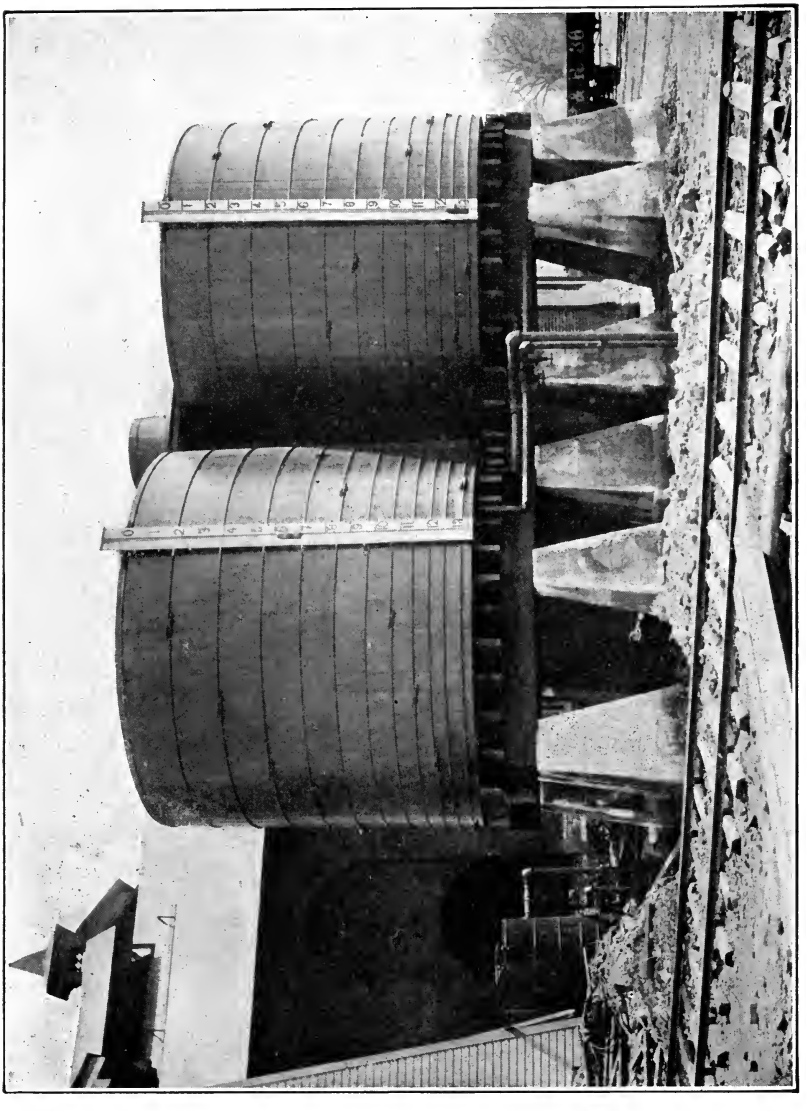
Another system of water-softening apparatus, designed by the N. Y. Continental Jewell Filtration Company, is known as the Intermittent type, so called because each tank of a series is filled, treated according to its individual requirements, and the water is entirely consumed before allowing any more raw water to enter the tank.

Tank *A* is filled with raw water, then the proper weight of chemical reagents are added and the mechanical agitator is set in operation until we obtain a complete mixture of the chemicals and water; the stirring is then stopped and the water comes to a state of rest, and must remain so for the complete precipitation of all the heavy particles of sediment to the bottom of the tank.

The water is drawn off near the surface by means of a floating outlet pipe; this water then flows through connecting piping to a filter, after passing which it is clear and ready for consumption.



(New York Continental Jewell Filtration Company.)
FIG. 56. — Automatic Continuous Water-softening Plant.



(New York Continental Jewell Filtration Company.)
FIG. 57.—Standard Intermittent Softener.

While this process has been going on in tank *A* tank *B* has been furnishing the water for consumption.

The operation is thus continued; first one tank then the other.

In one plant using this company's system of softening the analysis of water before and after treatment is:

	Grains per Gallon.	
	Before.	After.
Oxide of iron.	.630	
Carbonate of lime.	10.768	1.450
" " magnesia. . .	4.777	
Hydrate of magnesia. . . .	. . . . .	.870
Sulphate of soda.	. . . . .	1.802
" " lime.	1.725	
Chloride of sodium.	2.080	2.000
Grains per U. S. gallon. . .	19.981	6.172
Hardness, Clark, degs. F.	17.5	3.00

A typical installation of the We-fu-go system is that at the Lorain Steel Company's works, Lorain, Ohio.

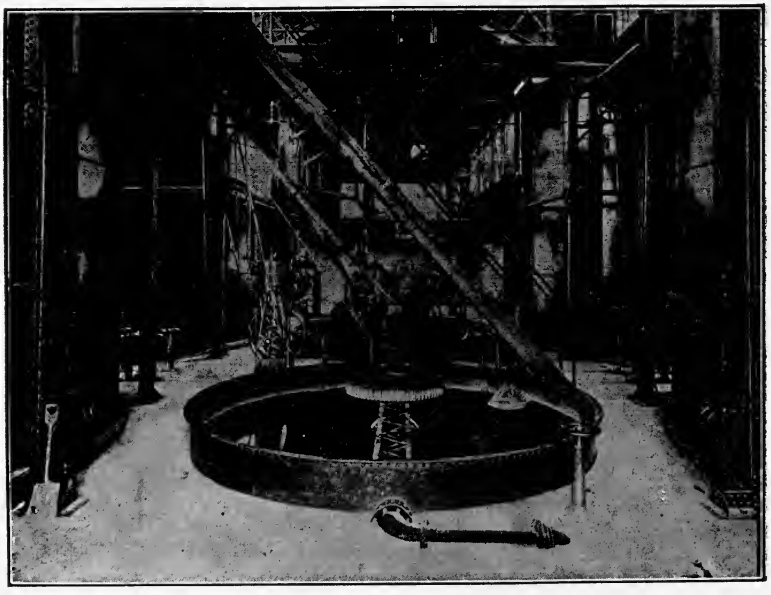


FIG. 58.—Operating Floor of the We-fu-go System (12,000 B.H.P). Lorain Steel Co., Lorain, Ohio.

In this plant the water supply first enters the settling- or chemical-treatment tank. A two-armed paddle near the bottom of this tank thoroughly mixes the chemicals and water. Water from the hot well of the blower-engine condensing-plant hastens the chemical reactions. From the treating-tank the water flows by gravity to the filters, where all impure solid matter which did not settle in treating-tank is removed. From here the water passes by gravity to the clean-water reservoir for storage, from which it is pumped to the heaters and steam-boilers.

A We-fu-go plant at Bloomington, Ill., on the Chicago & Alton R.R. is reported to soften water at a cost of about 6 cents per 1000 gallons.

A large plant, ultimately to soften from 3,000,000 to 4,000,000 gallons of water a day has been furnished the Tennessee Coal & Iron R.R. Company at Ensley, Ala., by the Pittsburg Filter Manufacturing Company; it treats water from village creek, which is especially bad duing the dry weather, as can be seen from this analysis:

	Grains per U. S. Gallon.
Sodium chloride	3.67
Calcium sulphate	12.47
Magnesium sulphate	11.00
Silica	4.02
Iron sulphate	6.53
Organic matter	1.92
Free sulphuric acid	9.81

The free sulphuric acid is due to pollution by manufacturing plants and may be *nil* in winter and early spring. Lime and soda-ash are the chemicals employed, and they are prepared separately in 600-gal. tanks; tanks are in duplicate. The solutions are run to the raw-water or precipitating tank, which after being filled is stirred up by compressed air at 10 to 20 pounds pressure, and after standing from one to four hours the clarified water is drawn down to 12 inches deep at the shallowest part. Sludge is flushed out to sewer as necessary. Two mechanical pressure-filters 20 feet in diameter by 8 feet high are used in this plant. The filters are washed out about once a week. Underneath the filters is a clear-water reservoir with a capacity of 18,000 gallons, from which the clear water for cleansing the filters is lifted by the centrifugal pumps.

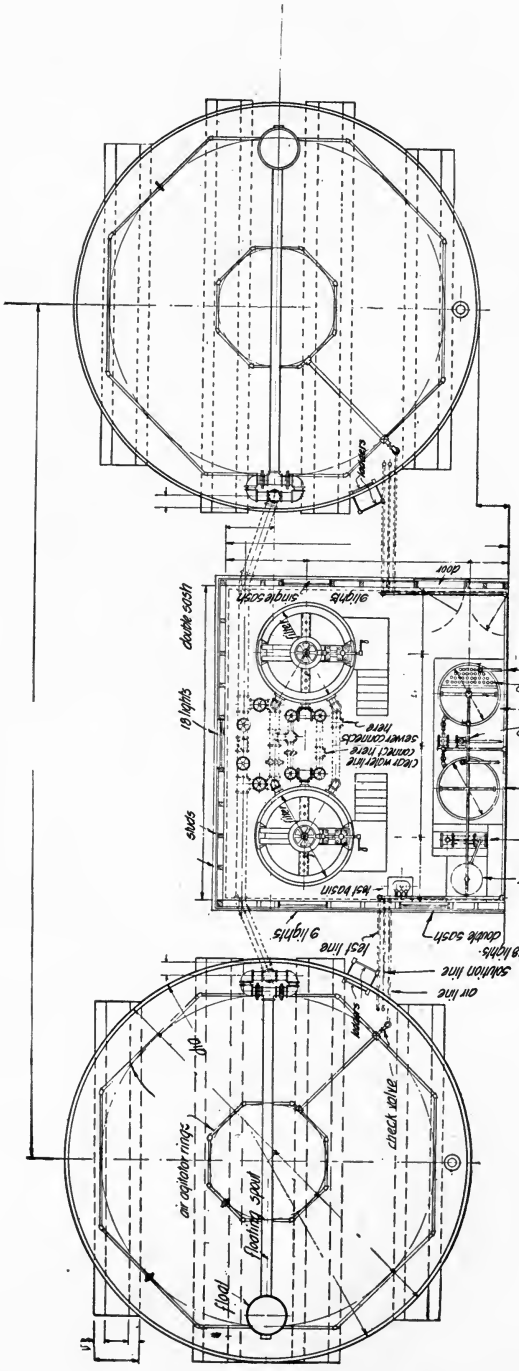
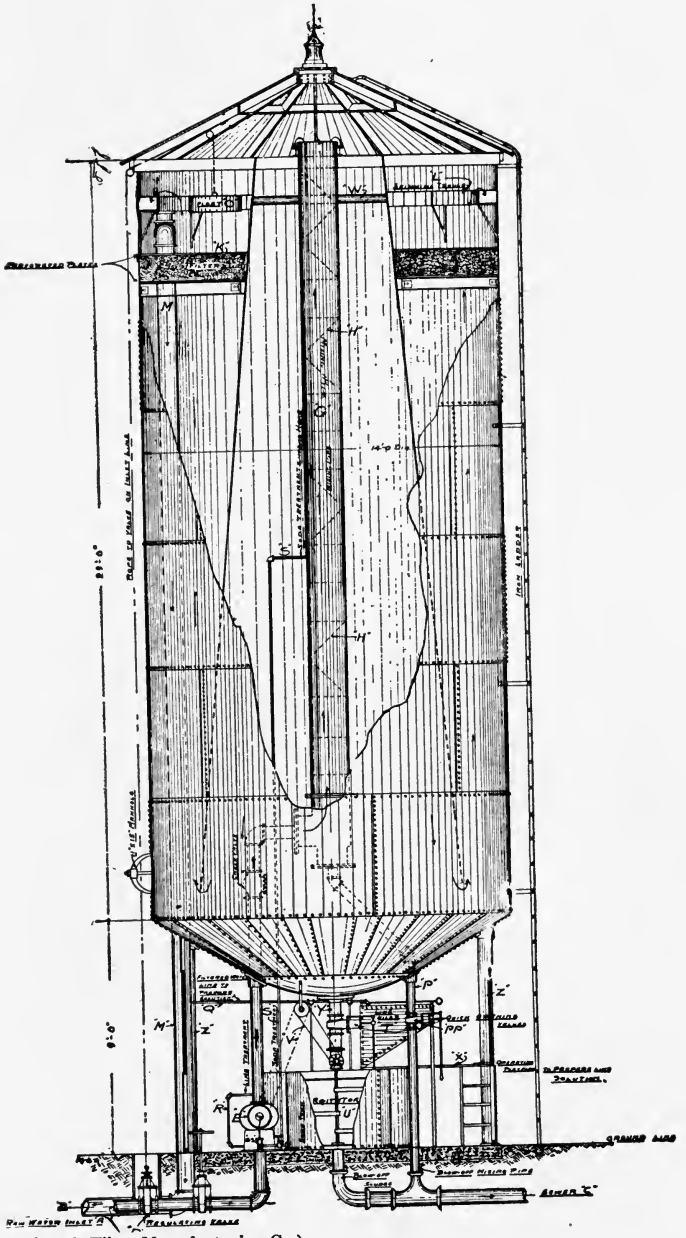


FIG. 59.—Intermittent Water-softener. (Pittsburgh Filter Mf'g Co., Pittsburgh, Pa.)



(Pittsburgh Filter Manufacturing Co.)

FIG. 60.—Continuous Water-softener.

As an example of municipal water-softening, one of the largest, if not the largest, plant now in operation is that designed by the Pittsburgh Testing Laboratory, Limited, at Winnipeg, Manitoba. Mr. James O. Handy, Chief Engineer of the laboratory, has furnished the following notes concerning it. The plant is illustrated by Figs. 60*a*, 60*b*, and 60*c*.

The Winnipeg Softening-plant.—The artesian-well water supplied to Winnipeg contains in its natural state the following elements in the amounts stated:

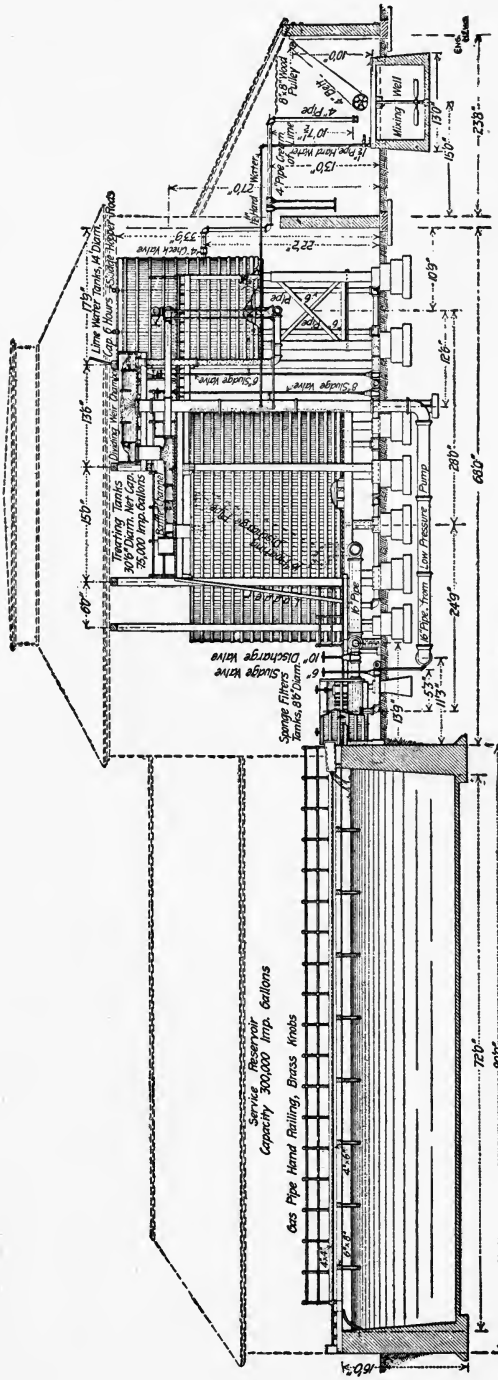
Carbonate of lime.	16.0	grains	per	imperial	gallon
" " magnesium..	8.5	"	"	"	"
Sulphate of magnesium. ..	12.0	"	"	"	"
" " sodium.....	5.5	"	"	"	"
Carbonate of sodium.....	3.0	"	"	"	"
Chloride of sodium.	27.5	"	"	"	"

Other compounds are present in minute amounts and are of no siginficance in this connection. The constituents mentioned have remained almost constant in kind and in quantity for over 2½ years. Of the constituents mentioned, only the first three cause the water to be hard. Of these three compounds, the softening process removes only the first two, i.e., the carbonates of lime and magnesium.

Sulphate of magnesium, while acting to some extent on soap, does not form any scale in boilers. In order to remove it from the water it would be necessary to add soda-ash as well as lime. This would involve expense and other objections out of proportion to the benefit gained.

The removal of the carbonates of lime and magnesium from the water eliminates a little over two-thirds of the hardening substances from the water. As explained above, the hardening substance which remains is the least harmful, so that the water is in reality more thoroughly softened than would at first appear to be the case.

For carrying out the softening process the arrangement is as follows: The hard water is delivered through a 16-inch pipe to a weir-box, or measuring device, at a point about 30 feet above the prairie level. Here the water divides automatically into two parts, always in the same ratio to each other. The smaller part is mixed continuously with cream of lime and made into lime-water, which


Longitudinal Section
Service Reservoir
Capacity 300,000 Imp. Gallons
Lime Water Tanks, 14 Diam.
Settling Tanks
Sponge Filters
Low Pressure Pump
Mixing Well
Hand Hoist
Sludge Valve
Discharge Valve
Cap. 6 Hours
Cap. 12 Hours
Cap. 24 Hours
Brass Knobs
Hand Railings,
Pipe
Pipe
Pipe

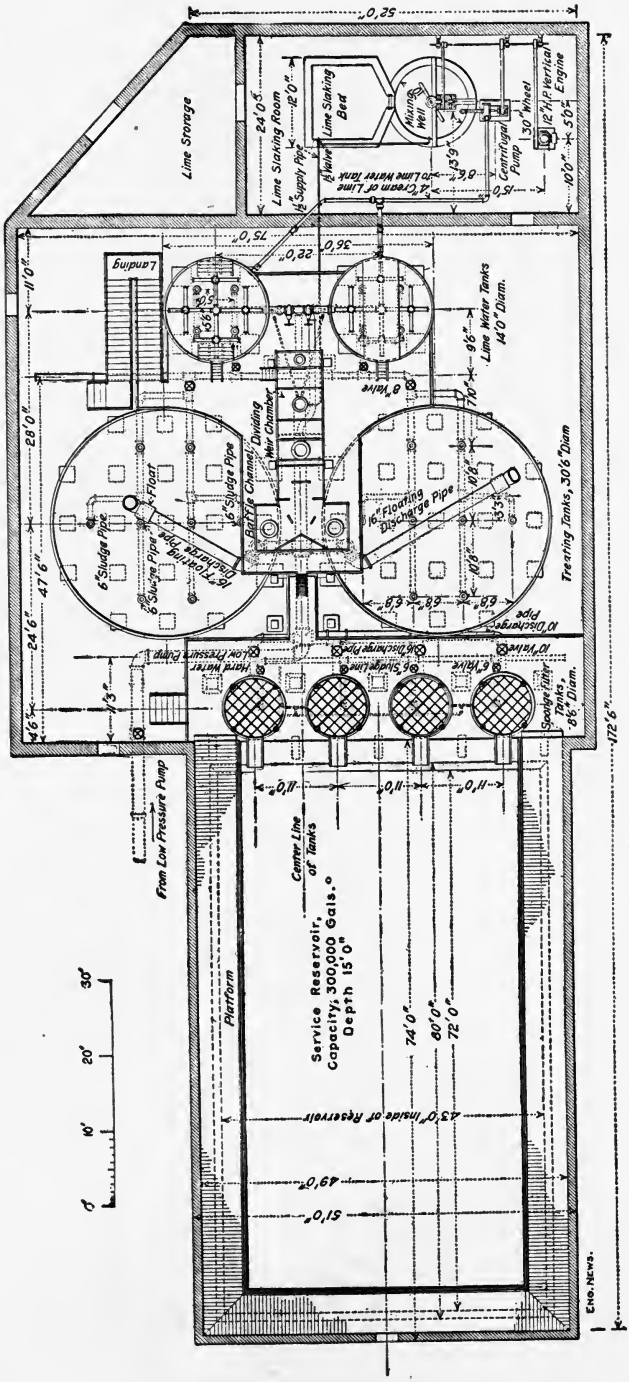


FIG. 60*b*.—Winnipeg, Manitoba, Water-softening Plant.

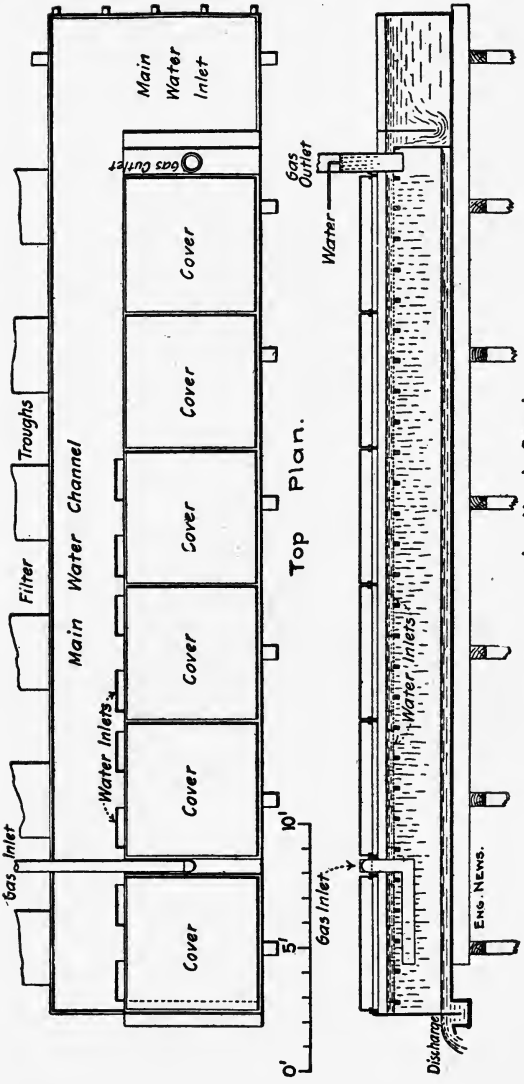


FIG. 60c.—Box for Carbonating Softened Water.

afterwards mixes with the hard water and softens it. As the making of the lime-water requires a little time, it is so arranged that the water just starting to be made into lime-water forces forward in a constant stream to mix with the hard water an exact equivalent amount of lime-water already formed. In other words, the water to be made into lime-water, as soon as it falls over the weir displaces lime-water already made. Mixed with cream of lime, it flows in at the bottom of the lime-water tanks, where it rises steadily and clarifies, and eventually flows forward to mix with the hard water. There is thus a steady stream of clarified lime-water being forced out of the lime-water tanks by the water which is entering below, and the amount of this stream is always proportional to the hard water which it is to soften. It is necessary, however, that the lime-water is always of the proper strength. Measured samples of lime-water are tested with a standard acid solution. If found under strength, cream of lime is supplied at a higher rate. If found over strength, the supply of cream of lime is diminished. Two gauges are on the side of the weir-box. One shows how much hard water is being pumped to the plant; the other shows how much cream of lime is being used for making lime-water. The amounts shown on the two gauges must be kept in a simple ratio to each other. When this is done very little testing is required.

The apparatus for preparing and pumping up the lime-cream consists of a slaking-bed, a mixing-well, and a ball-valve pump. The speed of the pump is regulated from the operating platform. The lime-water is mixed thoroughly with the hard water in a baffle-channel. Thence the turbid soft water flows to the bottom of two $20' \times 30'$ tanks, where it deposits nearly all of its suspended matter, or sludge. Rising slowly to the top, it flows off through floating discharge-pipes to the filters, which give it its final clarification. The softened water then flows to the carbonating box, where it meets purified carbonic-acid gas and absorbs it. This carbonated water flows into a 300,000-gallon reservoir, whence it is pumped to the city.

There are seven filters, each one containing about 1450 square feet of filter-cloth surface. Each filter runs about twenty-four hours. It is then opened and the cloths are removed, washed, and replaced.

Sludge Recovery.—On account of the high price of good lime in Winnipeg, the recovery of the waste lime from the softening process is being seriously considered. This would require a plant for purifying the sludge by removing the magnesia. Presses, drying apparatus, and special kilns would also be needed. It

FIG. 61.—Tweeddale System.—Section and Elevation.

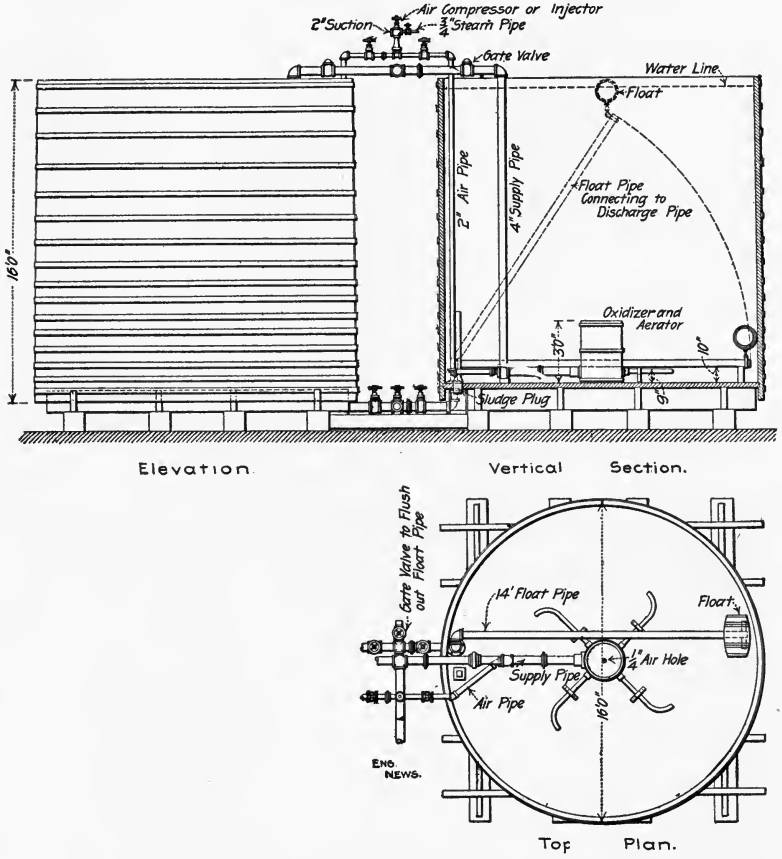


FIG. 62.—Tweeddale System.—Plan.

would be possible, however, to make high-grade lime for about one-third of what it is now costing.

The Tweeddale System, the invention of the late Wm. Tweeddale, of Topeka, Kan., is of the intermittent type, and is not automatic in its action, which features are said by its makers to

conduce to greater efficiency and likewise uniformity in results obtained. The process requires no pumps or machinery and needs a small amount of attention in every six hours when introducing the chemical solution and putting the aerating jets in action. The construction and arrangement are shown by Fig. 61. Two wooden tanks are used for treating purposes, while the other is pumped from or running to supply. Each holds 6 to 8 hours' supply; two 50,000-gallon tanks are used for a 2000 horse-power boiler capacity. Raw water enters the bottom of tank and passes to a filtering-chamber filled with coke and iron, then through 4 radial pipes with curved ends. When the tank is nearly full, air at 45 pounds pressure is forced through radial arms and a $\frac{1}{4}$-inch hole in the top (air may be supplied by compressor or steam-jet), which causes violent agitation of the water, and volatile and organic matter is said to be removed. After 5 minutes chemical reagents are poured in and agitated 15 minutes, then coagulant is added and 1 to 2 hours allowed for sedimentation. The sludge is allowed to accumulate to 5 or 6 inches in thickness, when it is washed out —say once in two or three weeks. It is also claimed that the stirring of the sludge by the air aids the settling. Treated water is removed from the top by means of a floating or swinging pipe fitted with a float. For railway plants this system uses one treating-tank only, the place of a second tank being taken by the railway regular supply-tank, into which the treated water is pumped after each batch of water has been purified.

Water at Topeka, Kan., Edison Illuminating Company's Station treated by this process gave results as follows:

	Grains per Gallon.	
	Before.	After.
Carbonate of lime	17.20	2.23
" " magnesia	10.05	1.45
Sulphate of lime	15.26	0.00
" " magnesia	0.00	0.51
" " iron	0.56	0.00
Silica	4.42	0.61
Oxide of iron	0.00	0.09
Organic matter	3.03	0.00
Alkali solids	20.33	21.51
Total solids	70.85	26.40
Total incrusting solids	50.52	4.89

In the **Scaife System** the feed-water first enters the heater, when it is heated to 200–210° F. A portion of the free carbonic acid is driven off by the heat; the bicarbonates of calcium and magnesia are precipitated as carbonates of these elements, the precipitation taking place on the heater trays or pans. A pump forces this hot water into a precipitating-tank, where the chemicals are introduced by means of two small pumps. Sometimes these chemicals are introduced into the feed-water on its way to the precipitation-tank. The scale-forming substances which

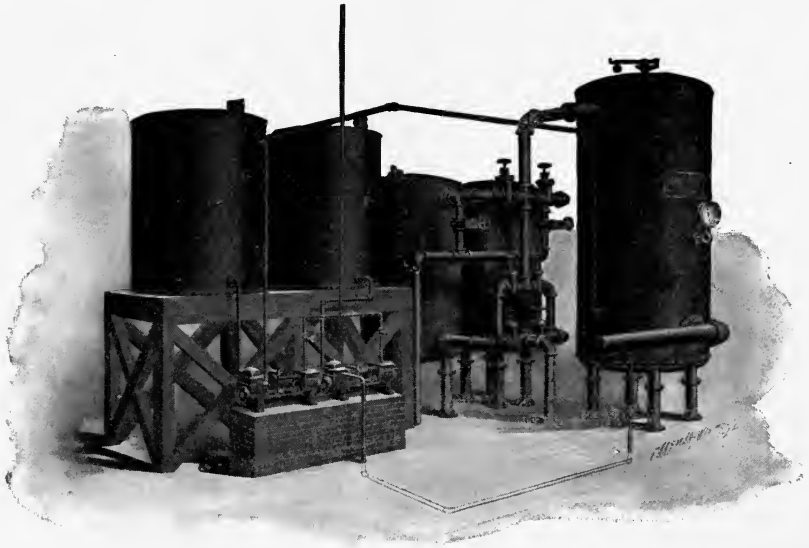


FIG. 63.—The Scaife System.

are precipitated in this tank sink to the bottom, from whence they are removed. Lighter substances pass on to the filters, which remove all suspended matter and gaseous or foul odors.

This system can be used with the closed type of heater, but in that event less of the carbonic acid can be removed than is the case with the open heater, which is to be preferred for use in connection with this system.

A system extensively used abroad and controlled here by its inventor, Mr. Halvor Breda, of Berlin, Germany, known as the **Breda System,** employs as chemical reagents slaked lime and soda.

Its distinctive feature, however, is in the heating of all water before treatment. Other features are automatic control of the flow of chemical solutions, design of lime-water saturator, and the independent mechanical filter. One of these plants, with a capacity of 1050 gallons per day, is installed at the factory of Wm. Demuth & Co., Brooklyn, N. Y.

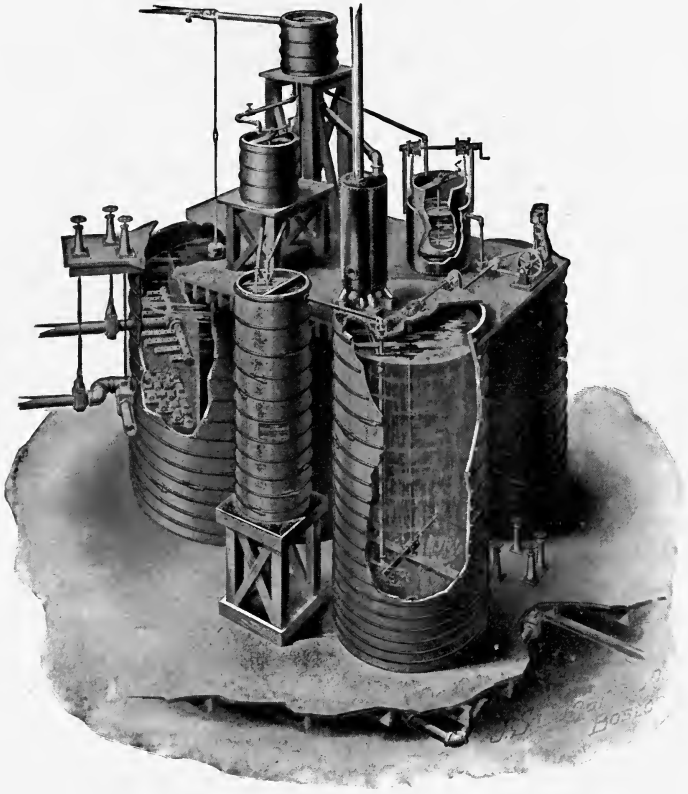


Fig. 64.—The We-fu-go Continuous System.

All the water enters the top of the distributor (Figs. 67, 68, and 69), when it is broken up by a perforated plate and sent its several ways. From the bottom of the water-heater and the top of the lime-saturator it goes to the central mixing compartment of settling-tank. The chemically charged water now goes to bot-

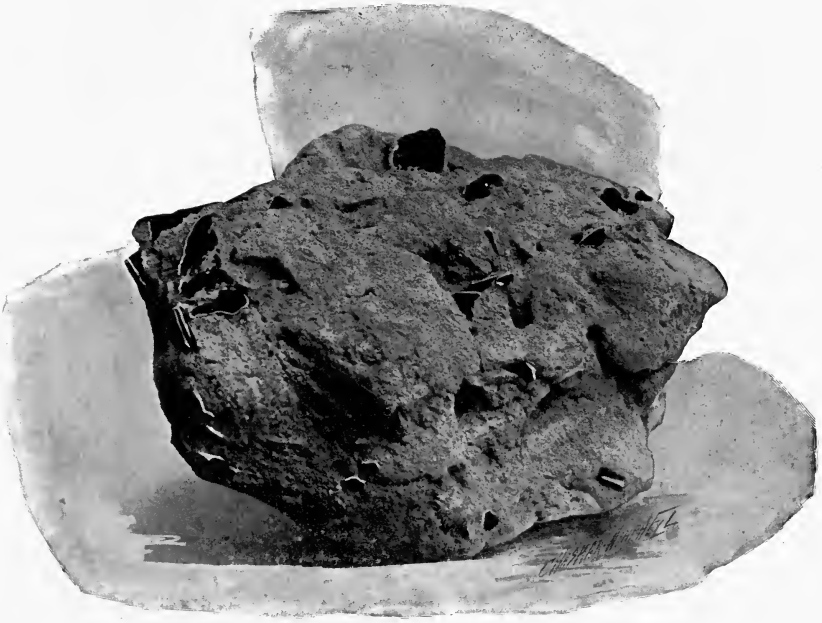


FIG. 65.—Sludge and Old Scale from Boilers Using Water from Scaife Softener.

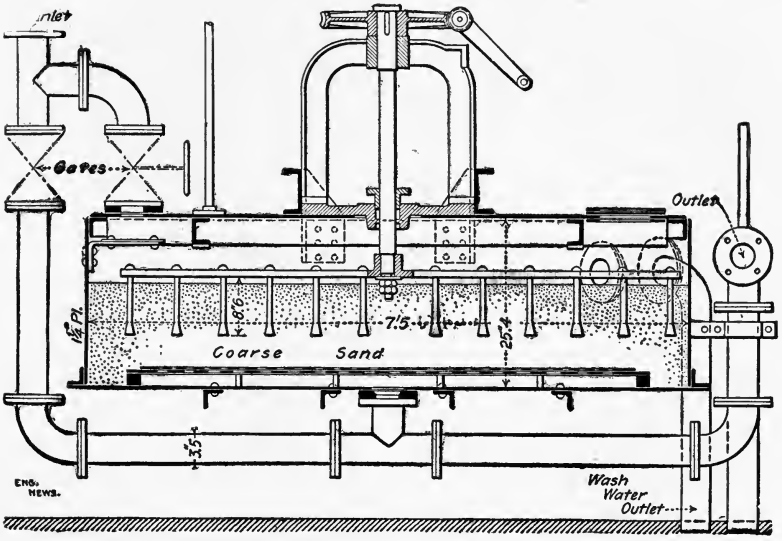


FIG. 66.—Section Through Filter of Breda System.

tom of settling-tank, then slowly up the outer clearing compartment, over a notched circular collecting-weir, and through pipe to

FIG. 67. FIG. 68.

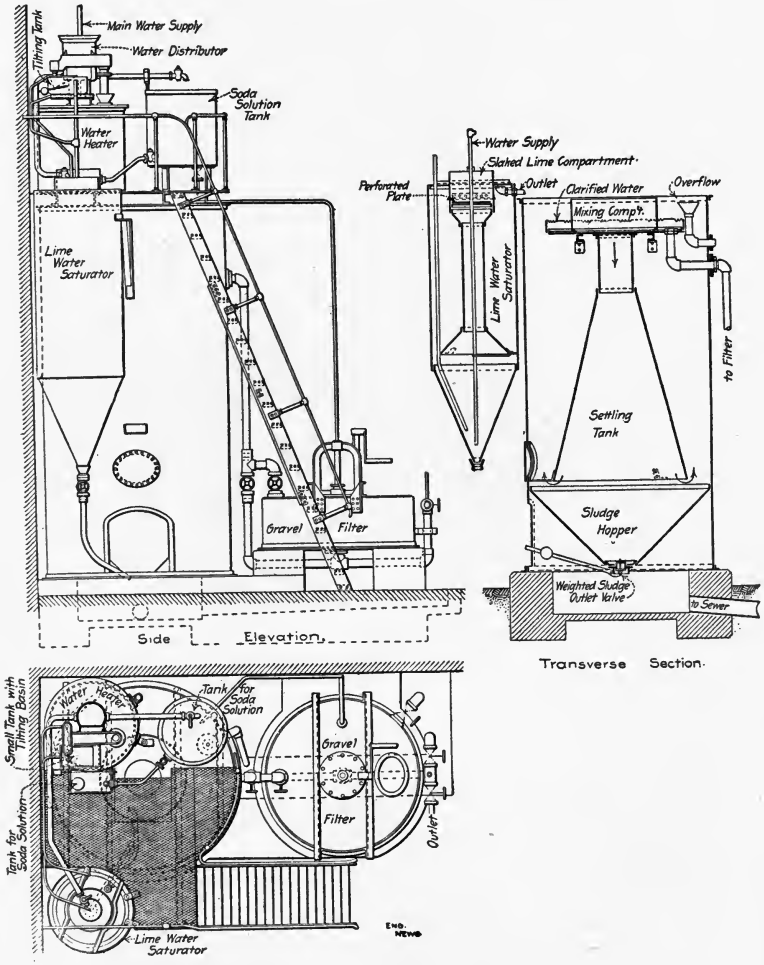


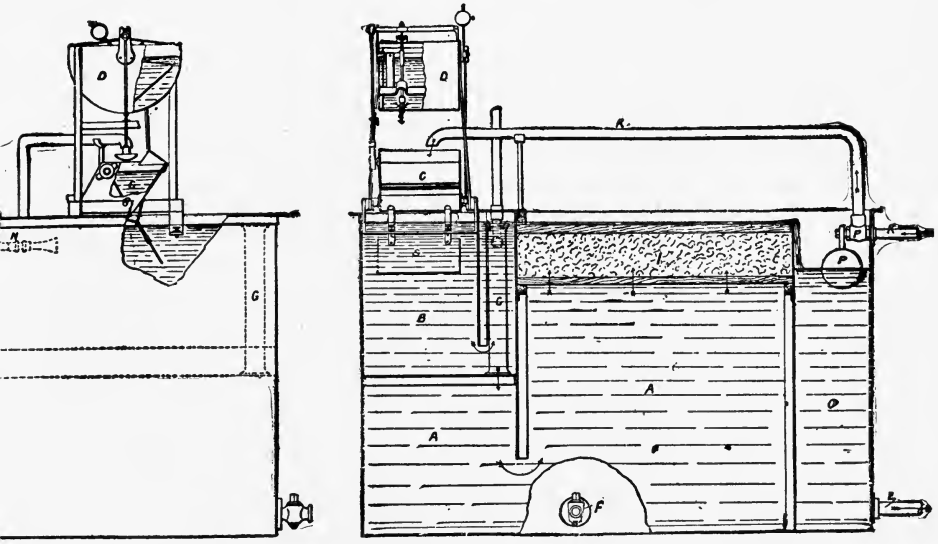
FIG. 69.

FIGS. 67, 68, and 69.—Breda System of Water Softening.

filter. By means of a tilting-basin, a soda solution is discharged five or six times per minute into the lime-tank. The filter is a fine gravel, mechanical-type filter (Fig. 66).

The Bruun-Lowener Water-softener (Figs. 70 and 71), manufactured by the American Water Softener Co., Philadephia, Pa., is one of the automatic type, requiring no motive power; it is also

FIG. 70.—Bruun-Lowener Softener



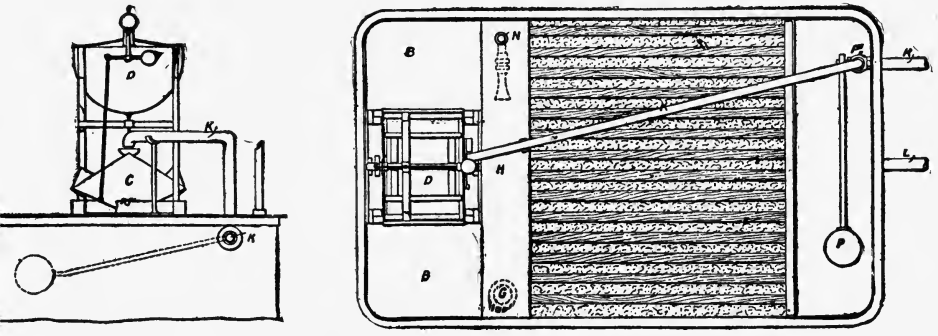


FIG. 71.—Bruun-Lowener Softener.

one in which the relative proportion of chemicals to crude water remains the same at all times.

The apparatus is entirely self-contained. Crude water enters

one of the chambers of the oscillating receiver C through the pipe K. A semi-circular tank D above C contains the chemicals, soda-ash, and lime; a valve in the bottom of D allows the chemicals to fall into the chamber of C, the oscillating receiver. The oscillation of this receiver by means of levers actuates the valve-outlet in D. The levers are provided with means of regulation of a quantity of chemicals. When one chamber of receiver C is filled, its center of gravity changes and the receiver tips and empties the water into the mixing-tank below, at the same time the other chamber is brought under the outlet of inlet-pipe K; when it fills the same operation is gone through with.

The lime-mi k used in this system is of 10 per cent strength; this is kept in constant motion by an agitator operated from oscillating receiver C. A plate S attached to the bottom of the receiver C keeps water and chemicals in mixing-tank B in motion. The mixture then passes to a heating-chamber H, where it is heated to, say, 140° F., to encourage precipitation of some scale-forming materials.

Where it is necessary to soften the water while cold, a larger settling-tank is required. The water runs from heating-chamber through by-pass G into settling-tank A, where precipitation is effected. Before the water leaves the softener it passes through the filter I, made of excelsior tightly packed between two rows of wooden bars, after which it runs to storage-tank O and is drawn off as required from pipe L. A ball valve P on pipe K regulates the flow of water to the oscillating receiver C.

Water for Locomotives.*—The Chicago, Milwaukee & St. Paul R.R. experimented for many years (1900) upon water for locomotives, and their chemists obtained results as follows.

Varieties of water may be classified by either of two methods:

1. By their chemical composition.
2. By their effect in use.

The second (2) is what interests steam users most.

In the first class (1) are placed

a. Alkaline waters.

b. Non-alkaline, bad and good.

---

* Stillman's Engrg. Chemistry.

In the second class (2)

a. Those causing foaming and corrosion but non-crusting.

b. Hard or incrusting.

c. Soft, non-alkaline and good.

These two classes are related in this wise: *a* of class 1, "alkaline" waters will produce the trouble mentioned in *a* of class 2; that is foaming, and in certain cases corrosion.

It is, however, impossible to set hard and fast limits for each class, one merging into the other, and what would be considered good water in the West might be thought bad in the East.

In the non-incrusting group is formed a variety of actions. A well-known property of alkali in water is to cause foaming and priming when sudden reduction of pressure occurs upon opening the throttle. The point at which this action begins to be apparent depends upon a number of circumstances.

With a boiler overworked and foul from mud it appears sooner than in one having ample heating-surface with moderate train load, uniform resistance and consequent regular consumption of steam.

With the non-incrusting salts are associated a few that are readily decomposed in contact with iron and attack it, causing gradual corrosion.

These are usually magnesium chlorides and sulphates, a very small amount of which, say 10 grains per gallon, should condemn the water.

Organic matter is supposed also to have this corrosive action, but in the presence of alkali the danger is not great and with frequent blowing out but little attention need be given it.

The water may be classified as follows:

1	to	10	grains of solids per gallon			soft water.
10	"	20	"	"	"	moderately hard water.
Above	25		"	"	"	very hard water.

"Boiler compounds" are used by this railroad company. Total alkali, including that in the "compound," is kept under 50 grains per gallon or trouble is liable to happen from foaming.

This "compound" is one part caustic soda and one-half part sodium carbonate. This water is surface water, in the forest region of Wisconsin at Wauvau.

		Grains per Gallon.
Incrusting matter	Oxide of iron	0.23
	Calcium carbonate	2.26
	" sulphate	0.46
	Total	2.95
Non-incrusting matter	Organic and volatile	3.15
	Alkaline chlorides	0.68
	Total	3.83
Total residue, solid		6.78

A Very Bad Boiler Feed-water.—The following is a non-alkaline, badly incrusting water from Lenox Creek, Dakota:

		Grains per Gallon.
Incrusting matter	Calcium carbonate	40.31
	Magnesium carbonate	7.17
	Total	47.48
Non-incrusting matter	Organic and volatile	14.34
	Magnesium sulphate	46.07
	Alkaline chlorides	1.31
	Total	61.72
Total residue, solid		109.20

This water is a difficult one to purify and soften, and is also high in organic matter.

We now give examples of an artesian well-water that is worthless for boiler-feed purposes:

		M.	N.
Incrusting matter	Calcium carbonate	61.85	180.00
	" sulphate	41.44	35.46
	Oxides	.....	5.00
	Total	103.29	220.46
Non-incrusting matter	Alkaline sulphates	64.83	150.92
	" chlorides	13.94	1.14
	Magnesium sulphate	.....	20.90
	Organic and volatile	.....	23.42
	Total	78.77	196.38
Total residue, solid		182.06	416.84

M is from Kimball, Dakota.
N is from a 130-foot well at Fargo, N. Dak.

On the western divisions of this road frequency of washing-out boilers is increased, doing so as often as once in 300 to 400 miles run. Hot water is always used, and the boiler is filled again with hot water—a very good practice. Fully 75 per cent of the number of cracked fire-box sheets are saved by this practice alone, and, of course, repairs are reduced and mileage of locomotive increased.

A water-softener producing 30,000 pounds of water per hour for locomotive feeding actually saved in fuel 5 tons of coal per week at $5 per ton; it also saved $750 repairs in six months.

Mr. W. H. Maw gives as an advantage of water-softening the ability to use "a pure water and to use boilers of the locomotive, multi-tubular and water-tube types." This advantage he considers as outweighing any question of the cost of softening. Filtration has been found to be most satisfactorily carried out when the filters were operated under atmospheric pressure. When working under pressure filters are liable to get choked, then the water penetrates the mass at the point of least resistance, and when the current of water is reversed for purposes of washing the same set of happenings are found.

Stromeyer and Barron are agreed that filters do not remove all the precipitated carbonate of lime in softening apparatus.

In one case a 6-inch diameter pipe conveyed 9000 gallons of water per hour on a cold-water service. This pipe soon had but a 3-inch diameter hole left in it from carbonate of lime incrusting the metal.

Mr. Wm. Brown, of Siemens Bros. & Co., says, that with feed-waters worked with exhaust steam, distributed zig-zag trays, so placed that a great deal of surface of the water was acted on by the steam and from which water was fed to the boilers at nearly steam temperature, they collected 2200 pounds of dry powder (calcium carbonate) for 2,600,000 English gallons of water (26,000,000 pounds) passed through between the cleanings.

Chipping and scraping of each boiler was thus delayed from a seven-week period to a twenty-one-week period, merely brushing them out at seven and fourteen weeks.

Water-softening by Boiling.—Tests to soften water by boiling under pressure, made under the direction of Mr. Nicholas

Knight,* show that the precipitation of calcium carbonate is the same, whether water is boiled under normal atmospheric pressure or under a pressure of six or seven atmospheres.

Precipitation of magnesium carbonate is increased at the greater pressure.

Lime-water, 6 to 1, removes 71.42 per cent of temporary hardness, while boiling under pressure removes only 63.5 per cent.

* *Eng. News*, Vol. 53, p. 311.

CHAPTER X.

TABLES.

TABLE I.*

CONVERSION OF MILLIGRAMMES PER KILOGRAMME INTO GRAINS PER U. S. GALLON OF 231 CUBIC INCHES.

One U. S. gallon of pure water at 60° F., weighed in air at 60° F., at atmospheric pressure of 30 inches of mercury, weighs 58,334.94640743 grains.†

Parts per Million.	Grains per U. S. Gallon.	Parts per Million.	Grains per U. S. Gallon.	Parts per Million.	Grains per U. S. Gallon.
1	0.058335	36	2.100058	71	4.141781
2	0.116670	37	2.158393	72	4.200116
3	0.175005	38	2.216728	73	4.258451
4	0.233340	39	2.275063	74	4.316786
5	0.291675	40	2.333398	75	4.375121
6	0.350010	41	2.391733	76	4.433456
7	0.408344	42	2.450068	77	4.491791
8	0.466679	43	2.508402	78	4.550126
9	0.525014	44	2.566737	79	4.608461
10	0.583349	45	2.625072	80	4.666796
11	0.641684	46	2.683407	81	4.725130
12	0.700019	47	2.741742	82	4.783465
13	0.758354	48	2.800077	83	4.841800
14	0.816689	49	2.858412	84	4.900135
15	0.875024	50	2.916747	85	4.958470
16	0.933359	51	2.975082	86	5.016805
17	0.991694	52	3.033417	87	5.075140
18	1.050029	53	3.091752	88	5.133475
19	1.108364	54	3.150087	89	5.191810
20	1.166699	55	3.208422	90	5.250145
21	1.225034	56	3.266757	91	5.308480
22	1.283369	57	3.325092	92	5.366815
23	1.341704	58	3.383427	93	5.425150
24	1.400039	59	3.441762	94	5.483485
25	1.458373	60	3.500097	95	5.541820
26	1.516708	61	3.558432	96	5.600155
27	1.575043	62	3.616766	97	5.658490
28	1.633378	63	3.675101	98	5.716825
29	1.691713	64	3.733436	99	5.775159
30	1.750048	65	3.791771	100	5.833494
31	1.808383	66	3.850106		
32	1.866718	67	3.908441		
33	1.925053	68	3.966776		
34	1.983388	69	4.025111		
35	2.041723	70	4.083446		

* Examination of Water. Wm. P. Mason

† See article by Mason on "The U. S. Gallon" in *Am. Druggist*, January, 1888.

TABLE II.

SAVING FROM HEATING FEED-WATER.

Initial Temperature Feed.	Temperature of Water Entering Boiler.											
	120°	130°	140°	150°	160°	170°	180°	190°	200°	210°	220°	250°
35°	7.24	8.09	8.95	9.89	10.66	11.52	12.38	13.24	14.09	14.95	15.81	19.40
40°	6.84	7.69	8.56	9.42	10.28	11.14	12.00	12.87	13.73	14.59	15.45	18.89
45°	6.44	7.30	8.16	9.03	9.90	10.76	11.62	12.49	13.36	14.22	15.09	18.37
50°	6.03	6.89	7.76	8.64	9.51	10.38	11.24	12.11	12.98	13.85	14.72	17.87
55°	5.63	6.49	7.37	8.24	9.11	9.99	10.85	11.73	12.60	13.48	14.35	17.38
60°	5.21	6.08	6.96	7.84	8.72	9.60	10.47	11.34	12.22	13.10	13.98	16.86
65°	4.80	5.67	6.56	7.44	8.32	9.20	10.08	10.96	11.84	12.72	13.60	16.35
70°	4.38	5.26	6.15	7.03	7.92	8.80	9.68	10.57	11.45	12.34	13.22	15.84
75°	3.97	4.84	5.73	6.62	7.51	8.40	9.28	10.17	11.06	11.95	12.84	15.33
80°	3.54	4.42	5.32	6.21	7.11	8.00	8.88	9.78	10.67	11.57	12.46	14.82
85°	3.11	4.00	4.90	5.80	6.70	7.59	8.48	9.38	10.28	11.18	12.07	14.32
90°	2.68	3.58	4.48	5.38	6.28	7.18	8.07	8.98	9.88	10.78	11.68	13.81
95°	2.25	3.15	4.05	4.95	5.86	6.77	7.66	8.57	9.47	10.38	11.29	13.31
100°	1.81	2.71	3.62	4.53	5.44	6.35	7.25	8.16	9.07	9.98	10.88	12.80

TABLE III.

FACTORS OF EVAPORATION.

Temp. of Feed.	Gauge Pressure, Pounds.								
	0	10	20	30	40	45	50	52	54
212° F.	1.0003	1.0088	1.0149	1.0197	1.0237	1.0254	1.0271	1.0277	1.0283
209	1.0035	1.0120	1.0180	1.0228	1.0268	1.0286	1.0302	1.0309	1.0315
206	1.0066	1.0151	1.0212	1.0260	1.0299	1.0317	1.0334	1.0340	1.0346
203	1.0098	1.0183	1.0243	1.0291	1.0331	1.0349	1.0365	1.0372	1.0378
200	1.0129	1.0214	1.0275	1.0323	1.0362	1.0380	1.0397	1.0403	1.0409
197	1.0160	1.0246	1.0306	1.0344	1.0394	1.0412	1.0428	1.0434	1.0441
194	1.0192	1.0277	1.0338	1.0385	1.0425	1.0443	1.0460	1.0466	1.0472
191	1.0223	1.0308	1.0369	1.0417	1.0457	1.0474	1.0491	1.0497	1.0503
188	1.0255	1.0340	1.0400	1.0448	1.0488	1.0506	1.0522	1.0528	1.0535
185	1.0286	1.0371	1.0432	1.0480	1.0519	1.0537	1.0554	1.0560	1.0566
182	1.0317	1.0403	1.0463	1.0511	1.0551	1.0568	1.0585	1.0591	1.0598
179	1.0349	1.0434	1.0495	1.0542	1.0582	1.0600	1.0616	1.0623	1.0629
176	1.0380	1.0465	1.0526	1.0574	1.0613	1.0631	1.0648	1.0654	1.0660
173	1.0411	1.0497	1.0557	1.0605	1.0645	1.0663	1.0679	1.0685	1.0692
170	1.0443	1.0528	1.0589	1.0636	1.0676	1.0694	1.0710	1.0717	1.0723
167	1.0474	1.0559	1.0620	1.0668	1.0707	1.0725	1.0742	1.0748	1.0754
164	1.0505	1.0591	1.0651	1.0699	1.0739	1.0756	1.0773	1.0780	1.0786
161	1.0537	1.0622	1.0682	1.0730	1.0770	1.0788	1.0804	1.0811	1.0817
158	1.0568	1.0653	1.0714	1.0762	1.0801	1.0819	1.0836	1.0842	1.0848
155	1.0599	1.0684	1.0745	1.0793	1.0833	1.0850	1.0867	1.0873	1.0880
152	1.0631	1.0716	1.0776	1.0824	1.0864	1.0882	1.0898	1.0905	1.0911
149	1.0662	1.0747	1.0808	1.0855	1.0895	1.0913	1.0930	1.0936	1.0942
146	1.0693	1.0778	1.0839	1.0887	1.0926	1.0944	1.0961	1.1967	1.0973
143	1.0724	1.0810	1.0870	1.0918	1.0958	1.0975	1.0992	1.0998	1.1005
140	1.0756	1.0841	1.0901	1.0949	1.0989	1.1007	1.1023	1.1030	1.1036
137	1.0787	1.0872	1.0933	1.0980	1.1020	1.1038	1.1055	1.1061	1.1067
134	1.0818	1.0903	1.0964	1.1012	1.1051	1.1069	1.1086	1.1092	1.1098
131	1.0849	1.0934	1.0995	1.1043	1.1083	1.1100	1.1117	1.1123	1.1130
128	1.0881	1.0966	1.1026	1.1074	1.1114	1.1132	1.1148	1.1155	1.1161
125	1.0912	1.0997	1.1057	1.1105	1.1145	1.1163	1.1179	1.1186	1.1192
122	1.0943	1.1028	1.1089	1.1136	1.1176	1.1194	1.1211	1.1217	1.1223
119	1.0974	1.1059	1.1120	1.1168	1.1207	1.1225	1.1242	1.1248	1.1254
116	1.1005	1.1090	1.1151	1.1199	1.1239	1.1256	1.1273	1.1279	1.1286
113	1.1036	1.1122	1.1182	1.1230	1.1270	1.1288	1.1304	1.1310	1.1317
110	1.1068	1.1153	1.1213	1.1261	1.1301	1.1319	1.1335	1.1342	1.1348
107	1.1099	1.1184	1.1245	1.1292	1.1332	1.1350	1.1366	1.1373	1.1379
104	1.1130	1.1215	1.1276	1.1323	1.1363	1.1381	1.1398	1.1404	1.1410
101	1.1161	1.1246	1.1307	1.1355	1.1394	1.1412	1.1429	1.1435	1.1441
98	1.1192	1.1277	1.1338	1.1386	1.1426	1.1443	1.1460	1.1466	1.1473
95	1.1223	1.1309	1.1369	1.1417	1.1457	1.1475	1.1491	1.1497	1.1504
92	1.1255	1.1340	1.1400	1.1448	1.1488	1.1506	1.1522	1.1529	1.1535
89	1.1286	1.1371	1.1431	1.1479	1.1519	1.1537	1.1553	1.1560	1.1566
86	1.1317	1.1402	1.1463	1.1510	1.1550	1.1568	1.1584	1.1591	1.1597
83	1.1348	1.1433	1.1494	1.1541	1.1581	1.1599	1.1616	1.1622	1.1628
80	1.1379	1.1464	1.1525	1.1573	1.1612	1.1630	1.1647	1.1653	1.1659
77	1.1410	1.1495	1.1556	1.1604	1.1644	1.1661	1.1678	1.1684	1.1690
74	1.1441	1.1526	1.1587	1.1635	1.1675	1.1692	1.1709	1.1715	1.1722
71	1.1472	1.1558	1.1618	1.1666	1.1706	1.1723	1.1740	1.1746	1.1753
68	1.1504	1.1589	1.1649	1.1697	1.1737	1.1755	1.1771	1.1778	1.1784
65	1.1535	1.1620	1.1680	1.1728	1.1768	1.1786	1.1802	1.1809	1.1815
62	1.1566	1.1651	1.1711	1.1759	1.1799	1.1817	1.1833	1.1840	1.1846
59	1.1597	1.1682	1.1743	1.1790	1.1830	1.1848	1.1864	1.1871	1.1877
56	1.1628	1.1713	1.1774	1.1821	1.1861	1.1879	1.1896	1.1902	1.1908
53	1.1659	1.1744	1.1805	1.1852	1.1892	1.1910	1.1927	1.1933	1.1939
50	1.1690	1.1775	1.1836	1.1884	1.1923	1.1941	1.1958	1.1964	1.1970
47	1.1721	1.1806	1.1867	1.1915	1.1954	1.1972	1.1989	1.1995	1.2001
44	1.1752	1.1837	1.1898	1.1946	1.1986	1.2003	1.2020	1.2026	1.2032
41	1.1783	1.1868	1.1929	1.1977	1.2017	1.2034	1.2051	1.2057	1.2064
38	1.1814	1.1900	1.1960	1.2008	1.2048	1.2065	1.2082	1.2088	1.2095
35	1.1845	1.1931	1.1991	1.2039	1.2079	1.2096	1.2113	1.2119	1.2126
32	1.1876	1.1962	1.2022	1.2070	1.2110	1.2128	1.2144	1.2151	1.2157

FACTORS OF EVAPORATION—*Continued.*

Temp. of Feed.	Gauge Pressure, Pounds.									
	56	58	60	65	70	75	80	85	90	95
212° F.	1.0290	1.0295	1.0301	1.0315	1.0329	1.0341	1.0353	1.0365	1.0376	1.0387
209	1.0321	1.0327	1.0333	1.0346	1.0360	1.0372	1.0385	1.0397	1.0408	1.0419
206	1.0352	1.0358	1.0364	1.0378	1.0391	1.0403	1.0416	1.0428	1.0439	1.0450
203	1.0384	1.0390	1.0396	1.0410	1.0423	1.0435	1.0448	1.0460	1.0471	1.0482
200	1.0415	1.0421	1.0427	1.0441	1.0454	1.0466	1.0479	1.0491	1.0502	1.0513
197	1.0447	1.0453	1.0458	1.0477	1.0486	1.0498	1.0511	1.0522	1.0533	1.0544
194	1.0478	1.0484	1.0490	1.0504	1.0517	1.0529	1.0542	1.0553	1.0565	1.0576
191	1.0510	1.0515	1.0521	1.0535	1.0549	1.0561	1.0573	1.0585	1.0596	1.0607
188	1.0541	1.0547	1.0553	1.0566	1.0580	1.0592	1.0605	1.0616	1.0628	1.0639
185	1.0572	1.0578	1.0584	1.0598	1.0611	1.0623	1.0636	1.0648	1.0659	1.0670
182	1.0604	1.0610	1.0615	1.0629	1.0643	1.0655	1.0668	1.0679	1.0690	1.0701
179	1.0635	1.0641	1.0647	1.0660	1.0674	1.0686	1.0699	1.0710	1.0722	1.0733
176	1.0666	1.0672	1.0678	1.0692	1.0705	1.0717	1.0730	1.0742	1.0753	1.0764
173	1.0698	1.0704	1.0709	1.0723	1.0737	1.0749	1.0762	1.0773	1.0784	1.0795
170	1.0729	1.0735	1.0741	1.0754	1.0768	1.0780	1.0793	1.0804	1.0816	1.0827
167	1.0760	1.0766	1.0772	1.0786	1.0799	1.0811	1.0824	1.0836	1.0847	1.0858
164	1.0792	1.0798	1.0803	1.0817	1.0831	1.0843	1.0856	1.0867	1.0878	1.0889
161	1.0823	1.0829	1.0835	1.0848	1.0862	1.0874	1.0887	1.0898	1.0910	1.0921
158	1.0854	1.0860	1.0866	1.0880	1.0893	1.0905	1.0918	1.0929	1.0941	1.0952
155	1.0886	1.0892	1.0897	1.0911	1.0925	1.0937	1.0949	1.0961	1.0972	1.0983
152	1.0917	1.0923	1.0929	1.0942	1.0956	1.0968	1.0981	1.0992	1.1004	1.1015
149	1.0948	1.0954	1.0960	1.0974	1.0987	1.0999	1.1012	1.1023	1.1035	1.1046
146	1.0979	1.0985	1.0991	1.1005	1.1018	1.1030	1.1043	1.1055	1.1066	1.1077
143	1.1011	1.1017	1.1022	1.1036	1.1050	1.1062	1.1074	1.1086	1.1097	1.1108
140	1.1042	1.1048	1.1054	1.1067	1.1081	1.1093	1.1106	1.1117	1.1129	1.1140
137	1.1073	1.1079	1.1085	1.1099	1.1112	1.1124	1.1137	1.1148	1.1160	1.1171
134	1.1104	1.1110	1.1116	1.1130	1.1143	1.1155	1.1168	1.1180	1.1191	1.1202
131	1.1136	1.1142	1.1147	1.1161	1.1175	1.1187	1.1199	1.1210	1.1222	1.1233
128	1.1167	1.1173	1.1179	1.1192	1.1206	1.1218	1.1231	1.1242	1.1253	1.1264
125	1.1198	1.1204	1.1210	1.1223	1.1237	1.1249	1.1262	1.1273	1.1285	1.1296
122	1.1229	1.1235	1.1241	1.1255	1.1268	1.1280	1.1293	1.1294	1.1316	1.1327
119	1.1260	1.1266	1.1272	1.1286	1.1299	1.1311	1.1324	1.1336	1.1347	1.1358
116	1.1292	1.1298	1.1303	1.1317	1.1331	1.1343	1.1355	1.1366	1.1378	1.1389
113	1.1323	1.1329	1.1334	1.1348	1.1362	1.1374	1.1387	1.1398	1.1409	1.1420
110	1.1354	1.1360	1.1366	1.1374	1.1393	1.1405	1.1418	1.1429	1.1441	1.1452
107	1.1385	1.1391	1.1397	1.1411	1.1424	1.1436	1.1449	1.1460	1.1472	1.1483
104	1.1416	1.1422	1.1428	1.1442	1.1455	1.1467	1.1480	1.1491	1.1503	1.1514
101	1.1447	1.1453	1.1459	1.1473	1.1486	1.1498	1.1511	1.1523	1.1534	1.1545
98	1.1479	1.1485	1.1490	1.1504	1.1518	1.1530	1.1542	1.1554	1.1565	1.1576
95	1.1510	1.1516	1.1521	1.1535	1.1549	1.1561	1.1574	1.1583	1.1596	1.1607
92	1.1541	1.1547	1.1553	1.1566	1.1580	1.1592	1.1605	1.1616	1.1628	1.1639
89	1.1572	1.1578	1.1584	1.1598	1.1611	1.1623	1.1636	1.1647	1.1659	1.1670
86	1.1603	1.1609	1.1615	1.1629	1.1642	1.1654	1.1667	1.1678	1.1690	1.1701
83	1.1634	1.1640	1.1646	1.1660	1.1673	1.1685	1.1698	1.1709	1.1721	1.1732
80	1.1665	1.1671	1.1677	1.1691	1.1704	1.1716	1.1729	1.1741	1.1752	1.1763
77	1.1696	1.1702	1.1708	1.1722	1.1735	1.1747	1.1760	1.1772	1.1783	1.1794
74	1.1728	1.1734	1.1739	1.1753	1.1767	1.1779	1.1791	1.1803	1.1814	1.1825
71	1.1759	1.1765	1.1770	1.1784	1.1798	1.1810	1.1823	1.1834	1.1845	1.1856
68	1.1790	1.1796	1.1802	1.1815	1.1829	1.1841	1.1854	1.1865	1.1877	1.1888
65	1.1821	1.1827	1.1833	1.1846	1.1860	1.1872	1.1885	1.1896	1.1908	1.1919
62	1.1852	1.1858	1.1864	1.1877	1.1891	1.1903	1.1916	1.1927	1.1939	1.1950
59	1.1883	1.1889	1.1895	1.1909	1.1922	1.1934	1.1947	1.1958	1.1970	1.1981
56	1.1914	1.1920	1.1926	1.1940	1.1953	1.1965	1.1978	1.1989	1.2001	1.2012
53	1.1945	1.1951	1.1957	1.1971	1.1984	1.1996	1.2009	1.2020	1.2032	1.2043
50	1.1976	1.1982	1.1988	1.2002	1.2015	1.2027	1.2040	1.2052	1.2063	1.2074
47	1.2007	1.2013	1.2019	1.2033	1.2046	1.2058	1.2071	1.2083	1.2094	1.2105
44	1.2039	1.2044	1.2050	1.2064	1.2078	1.2090	1.2102	1.2114	1.2125	1.2136
41	1.2070	1.2076	1.2081	1.2095	1.2109	1.2121	1.2133	1.2145	1.2156	1.2167
38	1.2101	1.2107	1.2112	1.2126	1.2140	1.2152	1.2164	1.2176	1.2187	1.2198
35	1.2132	1.2138	1.2143	1.2157	1.2171	1.2183	1.2196	1.2207	1.2118	1.2229
32	1.2163	1.2169	1.2175	1.2188	1.2202	1.2214	1.2227	1.2239	1.2249	1.2260

FACTORS OF EVAPORATION—*Continued.*

Temp. of Feed.	Gauge Pressure, Pounds.								
	100	105	115	125	135	145	155	165	185
212° F.	1.0397	1.1407	1.1427	1.0445	1.0462	1.0478	1.0493	1.0509	1.0536
209	1.0429	1.0438	1.0458	1.0476	1.0493	1.0509	1.0524	1.0540	1.0567
206	1.0460	1.0470	1.0489	1.0510	1.0527	1.0543	1.0558	1.0574	1.0601
203	1.0492	1.0502	1.0521	1.0540	1.0557	1.0573	1.0588	1.0604	1.0631
200	1.0523	1.0533	1.0552	1.0571	1.0588	1.0604	1.0619	1.0635	1.0662
097	1.0555	1.0565	1.0584	1.0602	1.0619	1.0635	1.0650	1.0666	1.0693
194	1.0586	1.0596	1.0615	1.0635	1.0652	1.0668	1.0683	1.0699	1.0726
191	1.0617	1.0627	1.0647	1.0665	1.0682	1.0698	1.0713	1.0729	1.0756
188	1.0649	1.0659	1.0678	1.0696	1.0713	1.0729	1.0744	1.0760	1.0787
185	1.0680	1.0690	1.0709	1.0728	1.0745	1.0761	1.0776	1.0792	1.0819
182	1.0712	1.0722	1.0741	1.0759	1.0776	1.0792	1.0807	1.0823	1.0850
179	1.0743	1.0753	1.0772	1.0790	1.0807	1.0823	1.0838	1.0854	1.0881
176	1.0774	1.0784	1.0803	1.0822	1.0839	1.0855	1.0870	1.0886	1.0913
173	1.0806	1.0816	1.0835	1.0853	1.0870	1.0886	1.0901	1.0917	1.0944
170	1.0837	1.0847	1.0866	1.0884	1.0901	1.0917	1.0932	1.0948	1.0975
167	1.0868	1.0878	1.0897	1.0916	1.0933	1.0949	1.0964	1.0980	1.1007
164	1.0900	1.0910	1.0929	1.0946	1.0963	1.0979	1.0994	1.1010	1.1037
161	1.0931	1.0941	1.0960	1.0979	1.0996	1.1012	1.1027	1.1043	1.1070
158	1.0962	1.0972	1.0991	1.1010	1.1027	1.1043	1.1058	1.1074	1.1101
155	1.0993	1.1003	1.1023	1.1041	1.1058	1.1074	1.1089	1.1105	1.1132
152	1.1025	1.1035	1.1054	1.1073	1.1090	1.1107	1.1122	1.1138	1.1165
149	1.1056	1.1066	1.1085	1.1103	1.1120	1.1136	1.1151	1.1167	1.1194
146	1.1087	1.1097	1.1116	1.1135	1.1152	1.1168	1.1183	1.1199	1.1226
143	1.1118	1.1129	1.1148	1.1166	1.1183	1.1199	1.1214	1.1230	1.1257
140	1.1150	1.1160	1.1179	1.1197	1.1214	1.1230	1.1245	1.1261	1.1288
137	1.1181	1.1191	1.1210	1.1228	1.1245	1.1262	1.1277	1.1293	1.1320
134	1.1212	1.1222	1.1241	1.1260	1.1277	1.1293	1.1308	1.1324	1.1351
131	1.1243	1.1253	1.1273	1.1291	1.1308	1.1324	1.1339	1.1355	1.1382
128	1.1275	1.1285	1.1304	1.1322	1.1339	1.1355	1.1370	1.1386	1.1413
125	1.1306	1.1316	1.1335	1.1353	1.1370	1.1386	1.1401	1.1417	1.1444
122	1.1337	1.1347	1.1366	1.1384	1.1401	1.1417	1.1438	1.1448	1.1475
119	1.1368	1.1378	1.1397	1.1415	1.1432	1.1449	1.1464	1.1480	1.1507
116	1.1399	1.1409	1.1429	1.1447	1.1464	1.1480	1.1495	1.1511	1.1538
113	1.1431	1.1441	1.1460	1.1478	1.1495	1.1511	1.1526	1.1542	1.1569
110	1.1462	1.1472	1.1491	1.1509	1.1516	1.1542	1.1557	1.1573	1.1600
107	1.1493	1.1503	1.1522	1.1540	1.1557	1.1573	1.1588	1.1604	1.1631
104	1.1524	1.1534	1.1553	1.1571	1.1588	1.1605	1.1619	1.1635	1.1662
101	1.1555	1.1565	1.1584	1.1602	1.1620	1.1636	1.1652	1.1668	1.1695
98	1.1586	1.1596	1.1616	1.1634	1.1651	1.1667	1.1683	1.1699	1.1726
95	1.1618	1.1628	1.1647	1.1665	1.1682	1.1698	1.1713	1.1729	1.1756
92	1.1649	1.1660	1.1678	1.1696	1.1713	1.1729	1.1744	1.1760	1.1787
89	1.1680	1.1690	1.1709	1.1727	1.1744	1.1760	1.1775	1.1791	1.1818
86	1.1711	1.1721	1.1740	1.1758	1.1775	1.1791	1.1806	1.1822	1.1849
83	1.1742	1.1752	1.1771	1.1789	1.1806	1.1823	1.1837	1.1853	1.1880
80	1.1773	1.1783	1.1802	1.1820	1.1837	1.1854	1.1869	1.1885	1.1912
77	1.1804	1.1814	1.1834	1.1852	1.1869	1.1885	1.1900	1.1916	1.1943
74	1.1835	1.1845	1.1865	1.1883	1.1900	1.1916	1.1932	1.1948	1.1975
71	1.1867	1.1877	1.1896	1.1914	1.1931	1.1947	1.1961	1.1977	1.2004
68	1.1898	1.1908	1.1927	1.1945	1.1962	1.1978	1.1993	1.2009	1.2036
65	1.1929	1.1939	1.1958	1.1976	1.1993	1.2009	1.2024	1.2040	1.2067
62	1.1960	1.1970	1.1989	1.2007	1.2024	1.2040	1.2055	1.2071	1.2098
59	1.1991	1.2001	1.2020	1.2038	1.2055	1.2071	1.2086	1.2102	1.2129
56	1.2022	1.2032	1.2051	1.2069	1.2086	1.2102	1.2117	1.2133	1.2160
53	1.2053	1.2063	1.2082	1.2100	1.2117	1.2134	1.2148	1.2164	1.2191
50	1.2084	1.2094	1.2113	1.2131	1.2148	1.2165	1.2180	1.2196	1.2223
47	1.2115	1.2125	1.2144	1.2163	1.2180	1.2196	1.2211	1.2227	1.2254
44	1.2146	1.2156	1.2176	1.2194	1.2211	1.2227	1.2242	1.2258	1.2285
41	1.2177	1.2187	1.2207	1.2225	1.2242	1.2258	1.2273	1.2289	1.2316
38	1.2208	1.2219	1.2238	1.2256	1.2273	1.2289	1.2304	1.2320	1.2347
35	1.2240	1.2250	1.2269	1.2287	1.2304	1.2320	1.2335	1.2351	1.2378
32	1.2271	1.2281	1.2300	1.2318	1.2335	1.2351	1.2366	1.2382	1.2409

TABLE IV.

PROPERTIES OF SATURATED STEAM.

Pounds per Square Inch		Temperature °F. at Pressure.	Heat Units in One Pound above 32° F.			Volume.		Weight of One Cubic Foot of Steam.
						Relative	Specific.	
Gauge Pressure.	Absolute Pressure.		h in the Water.	L Latent Heat of Vaporization	$H = L + h$ Total Heat in Steam.	Cu. Feet in 1 Cu. Foot of Water.	Cubic Feet in 1 Pound of Steam.	
.....	1	102	70.1	1042.9	1113.0	20623	330.4	.0030
.....	2	126.2	94.4	1026.0	1120.4	10730	171.9	.0058
.....	3	141.6	109.8	1015.2	1125.1	7325	117.3	.0085
.....	4	153.0	121.4	1007.2	1128.6	5588	89.51	.0112
.....	5	162.3	130.7	1000.7	1131.4	4530	72.56	.0138
.....	6	170.1	138.5	995.2	1133.8	3816	61.14	.0164
.....	7	176.9	145.4	990.4	1135.8	3302	52.89	.0189
.....	8	182.9	151.4	986.2	1137.7	2912	46.65	.0214
.....	9	188.3	156.9	982.4	1139.3	2607	41.77	.0239
.....	10	193.2	161.9	978.9	1140.8	2361	37.83	.0264
.....	11	197.7	166.5	975.7	1142.2	2159	34.59	.0289
.....	12	201.9	170.7	972.8	1143.5	1990	31.87	.0314
.....	13	205.8	174.7	970.0	1144.7	1845	29.56	.0338
.....	14	209.5	178.4	967.4	1145.8	1721	27.58	.0363
.304	15	213.0	181.9	964.9	1146.9	1614	25.85	.0387
1.3	16	216.3	185.2	962.6	1147.9	1519	24.33	.0411
2.3	17	219.4	188.4	960.4	1148.8	1434	22.98	.0435
3.3	18	222.3	191.4	958.3	1149.7	1359	21.72	.0459
4.3	19	225.2	194.2	956.3	1150.6	1292	20.70	.0483
5.3	20	227.9	197.0	954.4	1151.4	1231	19.73	.0507
6.3	21	230.5	199.6	952.5	1152.2	1176	18.84	.0531
7.3	22	233.0	202.2	950.8	1153.0	1126	18.04	.0554
8.3	23	235.4	204.6	949.0	1153.7	1080	17.30	.0578
9.3	24	237.7	207.0	947.4	1154.4	1038	16.62	.0602
10.3	25	240.0	209.3	945.8	1155.1	998.4	16.00	.0625
11.3	26	242.1	211.5	944.2	1155.8	962.3	15.42	.0649
12.3	27	244.2	213.6	942.7	1156.4	928.8	14.88	.0672
13.3	28	246.3	215.7	941.3	1157.0	897.6	14.38	.0695
14.3	29	248.3	217.7	939.9	1157.6	868.5	13.91	.0719
15.3	30	250.2	219.7	938.9	1158.2	841.3	13.48	.0742
16.3	31	252.1	221.6	937.1	1158.8	815.8	13.07	.0765
17.3	32	253.9	223.5	935.9	1159.3	791.8	12.68	.0788
18.3	33	255.7	225.3	934.6	1159.9	769.2	12.32	.0812
19.3	34	257.4	227.1	933.3	1160.4	748.0	11.98	.0835
20.3	35	259.1	228.8	932.1	1160.9	727.9	11.66	.0858
21.3	36	260.8	230.5	931.0	1161.5	708.8	11.37	.0881
22.3	37	262.4	232.1	929.8	1161.9	690.8	11.07	.0904
23.3	38	264.0	233.8	928.6	1162.4	673.7	10.79	.0927
24.3	39	265.6	235.3	927.5	1162.9	657.5	10.53	.0949
25.3	40	267.1	236.9	926.4	1163.4	642.0	10.28	.0972
26.3	41	268.6	238.4	925.4	1163.8	627.3	10.05	.0995
27.3	42	270.0	239.9	924.3	1164.3	613.3	9.826	.1018

PROPERTIES OF SATURATED STEAM—*Continued.*

Pounds per Square Inch.		Temperature ° F. at Pressure.	Heat Units in One Pound above 32° F.			Volume.		Weight of One Cubic Foot of Steam.
						Relative.	Specific.	
Gauge Pressure.	Absolute Pressure.		h in the Water.	L Latent Heat of Vaporization.	$H=L+h$ Total Heat in Steam.	Cu. Feet in 1 Cu. Foot of Water.	Cubic Feet in 1 Pound of Steam.	
28.3	43	271.5	241.4	923.3	1164.7	599.9	9.609	.1041
29.3	44	272.9	242.8	922.3	1165.1	587.0	9.403	.1063
30.3	45	274.3	244.2	921.3	1165.6	574.7	9.207	.1086
31.3	46	275.6	245.6	920.3	1166.0	563.0	9.018	.1109
32.3	47	276.9	247.0	919.4	1166.4	551.7	8.838	.1131
33.3	48	278.2	248.3	918.4	1166.8	540.9	8.665	.1154
34.3	49	279.5	249.6	917.5	1167.2	530.5	8.498	.1171
35.3	50	280.8	250.9	916.6	1167.6	520.5	8.338	.1199
36.3	51	282.1	252.2	915.7	1167.9	510.9	8.185	.1222
37.3	52	283.3	253.5	914.8	1168.3	501.7	8.037	.1244
38.3	53	284.5	254.7	913.9	1168.7	492.8	7.894	.1267
39.3	54	285.7	255.9	913.1	1169.0	484.2	7.756	.1289
40.3	55	286.9	257.1	912.2	1169.4	475.9	7.624	.1312
41.3	56	288.0	258.3	911.4	1169.7	467.9	7.496	.1334
42.3	57	289.1	259.5	910.6	1170.1	460.2	7.372	.1357
43.3	58	290.3	260.6	909.8	1170.4	452.7	7.252	.1379
44.3	59	291.4	261.7	909.0	1170.8	445.5	7.136	.1401
45.3	60	292.5	262.9	908.2	1171.1	438.5	7.024	.1424
46.3	61	293.6	264.0	907.4	1171.4	431.7	6.916	.1446
47.3	62	294.6	265.1	906.7	1171.8	425.2	6.811	.1468
48.3	63	295.7	266.1	905.9	1172.1	418.8	6.709	.1491
49.3	64	296.7	267.2	905.2	1172.4	412.6	6.610	.1513
50.3	65	297.7	268.3	904.4	1172.7	406.6	6.515	.1535
51.3	66	298.7	269.3	903.7	1173.0	400.8	6.422	.1557
52.3	67	299.7	270.3	903.0	1173.3	395.2	6.332	.1579
53.3	68	300.7	271.3	902.3	1173.6	389.8	6.244	.1602
54.3	69	301.7	272.3	901.5	1173.9	384.5	6.159	.1624
55.3	70	302.7	273.3	900.9	1174.2	379.3	6.076	.1646
56.3	71	303.6	274.3	900.2	1174.5	374.3	5.995	.1668
57.3	72	304.6	275.3	899.5	1174.8	369.4	5.917	.1690
58.3	73	305.5	276.2	898.8	1175.1	364.6	5.841	.1712
59.3	74	306.4	277.2	898.1	1175.4	360.0	5.767	.1734
60.3	75	307.3	278.1	897.5	1175.6	355.5	5.694	.1756
61.3	76	308.2	279.0	896.8	1175.9	351.1	5.624	.1778
62.3	77	309.1	280.0	896.2	1176.2	346.8	5.555	.1800
63.3	78	310.0	280.9	895.5	1176.5	342.6	5.488	.1822
64.3	79	310.9	281.8	894.9	1176.7	338.5	5.422	.1844
65.3	80	311.8	282.7	894.3	1177.0	334.5	5.358	.1866
66.3	81	312.6	283.5	893.7	1177.3	330.6	5.296	.1888
67.3	82	313.5	284.4	893.1	1177.5	326.8	5.235	.1910
68.3	83	314.3	285.3	892.4	1177.8	323.1	5.176	.1932
69.3	84	315.1	286.1	891.8	1178.0	319.5	5.118	.1954

PROPERTIES OF SATURATED STEAM—*Continued.*

Pounds per Square Inch.		Temperature ° F. at Pressure.	Heat Units in One Pound above 32° F.			Volume		Weight of One Cubic Foot of Steam.
						Relative.	Specific.	
Gauge Pressure.	Absolute Pressure.		h in the Water.	L Latent Heat of Vaporization.	$H=L+h$ Total Heat in Steam.	Cu. Feet in 1 Cu. Foot of Water.	Cubic Feet in 1 Pound of Steam.	
70.3	85	316.0	287.0	891.2	1178.3	315.9	5.061	.1976
71.3	86	316.8	287.8	890.6	1178.5	312.5	5.006	.1998
72.3	87	317.6	288.7	890.1	1178.8	309.1	4.951	.2020
73.3	88	318.4	289.5	889.5	1179.0	305.8	4.898	.2042
74.3	89	319.2	290.3	888.9	1179.3	302.5	4.846	.2063
75.3	90	320.0	291.1	888.3	1179.5	299.4	4.796	.2085
76.3	91	320.8	291.9	887.8	1179.8	296.3	4.746	.2107
77.3	92	321.6	292.7	887.2	1180.0	293.2	4.697	.2129
78.3	93	322.3	293.5	886.6	1180.2	290.2	4.650	.2151
79.3	94	323.1	294.3	886.1	1180.4	287.3	4.603	.2173
80.3	95	323.8	295.1	885.5	1180.7	284.5	4.557	.2194
81.3	96	324.6	295.9	885.0	1180.9	281.7	4.513	.2216
82.3	97	325.3	296.6	884.5	1181.1	279.0	4.469	.2238
83.3	98	326.1	297.4	883.9	1181.4	276.3	4.426	.2260
84.3	99	326.8	298.1	883.4	1181.6	273.7	4.384	.2281
85.3	100	327.5	298.9	882.9	1181.8	271.1	4.342	.2303
86.3	101	328.2	299.6	882.3	1182.0	268.5	4.302	.2325
87.3	102	329.0	300.4	881.8	1182.2	266.0	4.262	.2346
88.3	103	329.7	301.1	881.3	1182.5	263.6	4.223	.2368
89.3	104	330.4	301.8	880.8	1182.7	261.2	4.185	.2390
90.3	105	331.1	302.5	880.3	1182.9	258.9	4.147	.2411
91.3	106	331.8	303.3	879.8	1183.1	256.6	4.110	.2433
92.3	107	332.4	304.0	879.3	1183.3	254.3	4.074	.2455
93.3	108	333.1	304.7	878.8	1183.5	252.1	4.038	.2476
94.3	109	333.8	305.4	878.3	1183.7	249.9	4.003	.2498
95.3	110	334.5	306.1	877.8	1183.9	247.8	3.969	.2519
96.3	111	335.1	306.8	877.3	1184.1	245.7	3.935	.2541
97.3	112	335.8	307.4	876.9	1184.3	243.6	3.902	.2563
98.3	113	336.5	308.1	876.4	1184.5	241.6	3.870	.2584
99.3	114	337.1	308.8	875.9	1184.7	239.6	3.838	.2606
100.3	115	337.8	309.5	875.4	1184.9	237.6	3.806	.2627
101.3	116	338.4	310.1	875.0	1185.1	235.7	3.775	.2649
102.3	117	339.1	310.8	874.5	1185.3	233.8	3.745	.2670
103.3	118	339.7	311.4	874.0	1185.5	231.9	3.715	.2692
104.3	119	340.3	312.1	873.6	1185.7	230.1	3.685	.2713
105.3	120	340.9	312.7	873.1	1185.9	228.3	3.656	.2735
106.3	121	341.6	313.4	872.7	1186.1	226.5	3.628	.2757
107.3	122	342.2	314.0	872.5	1186.3	224.7	3.600	.2778
108.3	123	342.8	314.7	871.8	1186.5	223.0	3.572	.2800
109.3	124	343.4	315.3	871.3	1186.6	221.3	3.545	.2821
110.3	125	344.0	315.9	870.9	1186.8	219.6	3.518	.2842
111.3	126	344.6	316.6	870.4	1187.0	218.0	3.492	.2864

PROPERTIES OF SATURATED STEAM—*Continued.*

Pounds per Square Inch.		Temperature ° F. at Pressure.	Heat Units in One Pound above 32° F.			Volume.		Weight of One Cubic Foot of Steam.
						Relative.	Specific.	
Gauge Pressure.	Absolute Pressure.		h in the Water.	L Latent Heat of Vaporization.	$H=L+h$ Total Heat in Steam.	Cu. Feet in 1 Cu. Foot of Water.	Cubic Feet in 1 Pound of Steam.	
112.3	127	345.2	317.2	870.0	1187.2	216.4	3.466	.2885
113.3	128	345.8	317.8	869.6	1187.4	214.8	3.440	.2907
114.3	129	346.4	318.4	869.1	1187.6	213.2	3.415	.2928
115.3	130	347.0	319.0	868.7	1187.8	211.6	3.390	.2950
116.3	131	347.6	319.6	868.3	1187.9	210.1	3.366	.2971
117.3	132	348.2	320.2	867.8	1188.1	208.6	3.342	.2992
118.3	133	348.8	320.8	867.4	1188.3	207.1	3.318	.3014
119.3	134	349.3	321.4	867.0	1188.5	205.7	3.295	.3035
120.3	135	349.9	322.0	866.6	1188.6	204.2	3.272	.3057
121.3	136	350.5	322.6	866.2	1188.8	202.8	3.249	.3078
122.3	137	351.0	323.2	865.7	1189.0	201.4	3.227	.3099
123.3	138	351.7	323.8	865.3	1189.1	200.0	3.204	.3121
124.3	139	352.2	324.3	864.9	1189.3	198.7	3.182	.3142
125.3	140	352.7	324.9	864.5	1189.5	197.3	3.161	.3163
126.3	141	353.3	325.5	864.1	1189.7	196.0	3.140	.3185
127.3	142	353.8	326.1	863.7	1189.8	194.7	3.119	.3206
128.3	143	354.4	326.8	863.3	1190.0	193.4	3.099	.3227
129.3	144	354.9	327.2	862.9	1190.2	192.2	3.078	.3249
130.3	145	355.5	327.8	862.5	1190.3	190.9	3.058	.3270
131.3	146	356.0	328.3	862.1	1190.4	189.7	3.038	.3291
132.3	147	356.5	328.9	861.7	1190.6	188.5	3.019	.3313
133.3	148	357.1	329.4	861.4	1190.8	187.3	3.000	.3334
134.3	149	357.6	330.0	861.0	1191.0	186.1	2.981	.3355
135.3	150	358.1	330.5	860.6	1191.1	184.9	2.962	.3376
136.3	151	358.6	331.1	860.2	1191.3	183.7	2.943	.3398
137.3	152	359.2	331.6	859.8	1191.4	182.6	2.925	.3419
138.3	153	359.7	332.2	859.4	1191.6	181.5	2.908	.3439
139.3	154	360.2	332.7	859.1	1191.8	180.4	2.890	.3460
140.3	155	360.7	333.2	858.7	1191.9	179.2	2.870	.3484
141.3	156	361.2	333.7	858.3	1192.1	178.1	2.853	.3505
142.3	157	361.7	334.3	857.9	1192.2	177.0	2.835	.3526
143.3	158	362.2	334.8	857.6	1192.4	176.0	2.819	.3547
144.3	159	362.7	335.3	857.2	1192.5	174.9	2.802	.3568
145.3	160	363.2	335.8	856.8	1192.7	173.9	2.786	.3589
146.3	161	363.7	336.3	856.5	1192.8	172.9	2.770	.3610
147.3	162	364.2	336.9	856.1	1193.0	171.9	2.754	.3631
148.3	163	364.7	337.4	855.7	1193.1	171.0	2.739	.3650
149.3	164	365.2	337.9	855.4	1193.3	170.0	2.723	.3672
150.3	165	365.7	338.4	855.0	1193.5	169.0	2.707	.3693
151.3	166	366.2	338.9	854.7	1193.6	168.1	2.693	.3714
152.3	167	366.7	339.4	854.3	1193.7	167.1	2.677	.3735
153.3	168	367.1	339.9	853.9	1193.9	166.2	2.662	.3756

PROPERTIES OF SATURATED STEAM—*Continued.*

Pounds per Square Inch.		Temperature ° F. at Pressure.	Heat Units in One Pound above 32° F.			Volume.		Weight of One Cubic Foot of Steam.
						Relative.	Specific.	
Gauge Pressure.	Absolute Pressure.		h in the Water.	L Latent Heat of Vaporization.	$H=L+h$ Total Heat in Steam.	Cu. Feet in 1 Cu. Foot of Water.	Cubic Feet in 1 Pound of Steam.	
151.3	169	367.6	340.4	853.6	1194.0	165.3	2.648	.3777
155.3	170	368.1	340.9	853.2	1194.2	164.3	2.632	.3799
156.3	171	368.6	341.4	852.9	1194.3	163.4	2.617	.3820
157.3	172	369.1	341.9	852.6	1194.5	162.5	2.603	.3842
158.3	173	369.5	342.4	852.2	1194.6	161.6	2.588	.3863
159.3	174	370.0	342.8	851.9	1194.8	160.7	2.574	.3885
160.3	175	370.5	343.3	851.5	1194.9	159.8	2.560	.3906
161.3	176	370.9	343.8	851.2	1195.0	158.9	2.545	.3928
162.3	177	371.4	344.3	850.8	1195.2	158.1	2.533	.3949
163.3	178	371.9	344.8	850.5	1195.3	157.2	2.518	.3970
164.3	179	372.3	345.3	850.2	1195.5	156.4	2.505	.3991
165.3	180	372.8	345.7	849.8	1195.6	155.6	2.493	.4012
166.3	181	373.2	346.2	849.5	1195.7	154.8	2.480	.4033
167.3	182	373.7	346.7	849.2	1195.9	154.0	2.467	.4054
168.3	183	374.1	347.1	848.8	1196.0	153.2	2.455	.4075
169.3	184	374.6	347.6	848.5	1196.2	152.4	2.441	.4096
170.3	185	375.0	348.1	848.2	1196.3	151.6	2.428	.4118
171.3	186	375.5	348.6	847.8	1196.4	150.8	2.416	.4140
172.3	187	375.9	349.0	847.5	1196.6	150.0	2.403	.4162
173.3	188	376.4	349.5	847.2	1196.7	149.2	2.390	.4183
174.3	189	376.8	349.9	846.9	1196.8	148.5	2.379	.4204
175.3	190	377.2	350.4	846.5	1197.0	147.8	2.367	.4225
176.3	191	377.7	350.8	846.2	1197.1	147.0	2.355	.4246
177.3	192	378.1	351.3	845.9	1197.2	146.3	2.344	.4267
178.3	193	378.5	351.7	845.6	1197.4	145.6	2.332	.4287
179.3	194	379.0	352.2	845.3	1197.5	144.9	2.321	.4308
180.3	195	379.4	352.6	845.0	1197.6	144.2	2.310	.4329
181.3	196	379.9	353.1	844.6	1197.8	143.5	2.299	.4350
182.3	197	380.3	353.5	844.3	1197.9	142.8	2.287	.4372
183.3	198	380.7	354.0	844.0	1198.0	142.1	2.276	.4393
184.3	199	381.1	354.4	843.7	1198.1	141.4	2.265	.4414
185.3	200	381.5	354.8	843.4	1198.3	140.8	2.255	.4435
186.3	201	381.9	355.3	843.1	1198.4	140.1	2.244	.4456
187.3	202	382.4	355.7	842.8	1198.5	139.5	2.235	.4477
188.3	203	382.8	356.1	842.5	1198.7	138.8	2.223	.4498
189.3	204	383.2	356.6	842.2	1198.8	138.1	2.212	.4520
190.3	205	383.6	357.0	841.8	1198.9	137.5	2.203	.4540
191.3	206	384.0	357.4	841.5	1199.0	136.9	2.193	.4560
192.3	207	384.4	357.9	841.2	1199.2	136.3	2.183	.4580
193.3	208	384.8	358.3	841.0	1199.3	135.7	2.174	.4600
194.3	209	385.2	358.7	840.7	1199.4	135.1	2.164	.4621
195.3	210	385.6	359.1	840.4	1199.5	134.5	2.154	.4642

PROPERTIES OF SATURATED STEAM—*Continued.*

Pounds per Square Inch.		Temperature ° F. at Pressure.	Heat Units in One Pound above 32° F.			Volume.		Weight of One Cubic Foot of Steam.
						Relative.	Specific.	
Gauge Pressure.	Absolute Pressure.		h in the Water.	L Latent Heat of Vaporization.	$H = L + h$ Total Heat in Steam.	Cu. Feet in 1 Cu. Foot of Water.	Cubic Feet in 1 Pound of Steam.	
196.3	211	386.1	359.6	840.1	1199.7	133.9	2.145	.4663
197.3	212	386.5	360.0	839.8	1199.8	133.3	2.135	.4684
198.3	213	386.9	360.4	839.5	1199.9	132.8	2.126	.4705
199.3	214	387.3	360.9	839.2	1200.1	132.2	2.117	.4726
200.3	215	387.7	361.3	838.9	1200.2	131.6	2.108	.4747
201.3	216	388.1	361.7	838.6	1200.3	131.0	2.098	.4768
202.3	217	388.5	362.1	838.3	1200.4	130.4	2.089	.4789
203.3	218	388.9	362.5	838.0	1200.5	129.9	2.080	.4810
204.3	219	389.3	362.9	837.8	1200.7	129.3	2.070	.4831
205.3	220	389.6	363.3	837.5	1200.8	128.7	2.061	.4852
206.3	221	390.1	363.7	837.3	1201.0	128.1	2.052	.4873
207.3	222	390.5	364.1	837.0	1201.1	127.6	2.043	.4894
208.3	223	390.8	364.5	836.7	1201.2	127.0	2.035	.4915
209.3	224	391.2	364.9	836.4	1201.3	126.5	2.027	.4936
210.3	225	391.6	365.3	836.1	1201.4	126.0	2.018	.4956
211.3	226	392.0	365.8	835.8	1201.6	125.4	2.010	.4977
212.3	227	392.4	366.1	835.6	1201.7	124.9	2.002	.4998
213.3	228	392.8	366.5	835.3	1201.8	124.4	1.993	.5019
214.3	229	393.2	366.9	835.0	1201.9	123.9	1.984	.5040
215.3	230	393.5	367.3	834.7	1202.0	123.3	1.976	.5061
216.3	231	393.9	367.7	834.4	1202.1	122.9	1.968	.5082
217.3	232	394.3	368.1	834.1	1202.2	122.4	1.960	.5103
218.3	233	394.7	368.5	833.9	1202.4	121.9	1.952	.5124
219.3	234	395.1	368.9	833.6	1202.5	121.4	1.944	.5145
220.3	235	395.5	369.2	833.4	1202.6	120.9	1.936	.5165
221.3	236	395.9	369.6	833.1	1202.7	120.4	1.928	.5186
222.3	237	396.3	832.8	370.0	1202.8	119.9	1.921	.5207
223.3	238	396.6	832.5	370.4	1202.9	119.4	1.913	.5228
224.3	239	397.0	832.2	370.8	1203.0	119.0	1.905	.5249
225.3	240	397.4	832.0	371.1	1203.1	118.5	1.898	.5270
226.3	241	397.8	831.7	371.5	1203.2	118.0	1.891	.5291
227.3	242	398.1	831.4	371.9	1203.3	117.5	1.884	.5312
228.3	243	398.5	831.1	372.3	1203.4	117.1	1.857	.5332
229.3	244	398.9	830.8	372.7	1203.5	116.7	1.868	.5353
230.3	245	399.2	830.6	373.1	1203.7	116.2	1.861	.5374
231.3	246	399.6	830.4	373.4	1203.8	115.7	1.853	.5395
232.3	247	400.0	830.1	373.8	1203.9	115.3	1.846	.5416
233.3	248	400.3	829.8	374.2	1204.0	114.9	1.839	.5436
234.3	249	400.7	829.5	374.6	1204.1	114.4	1.832	.5457
235.3	250	401.1	829.2	375.0	1204.2	114.0	1.825	.5478
238.3	253	402.1	828.5	376.0	1204.5	112.7	1.806	.5540
241.3	256	403.1	827.9	377.0	1204.9	111.4	1.785	.5603

PROPERTIES OF SATURATED STEAM—*Continued.*

Pounds per Square Inch.		Temperature ° F. at Pressure.	Heat Units in One Pound above 32° F.			Volume.		Weight of One Cubic Foot of Steam.
Gauge Pressure.	Absolute Pressure.		h in the Water.	L Latent Heat of Vaporization.	$H = L + h$ Total Heat in Steam.	Relative. Cu. Feet in 1 Cu. Foot of Water.	Specific. Cubic Feet in 1 Pound of Steam.	
244.3	259	404.2	827.1	378.1	1205.2	110.2	1.766	.5665
247.3	262	405.2	826.3	379.2	1205.5	109.2	1.746	.5727
250.3	265	406.1	825.6	380.2	1205.8	107.8	1.728	.5789
253.3	268	407.2	824.9	381.2	1206.1	106.7	1.709	.5852
256.3	271	408.1	824.1	382.3	1206.4	105.6	1.691	.5914
259.3	274	409.1	823.4	383.3	1206.7	104.5	1.673	.5976
262.3	277	410.0	822.7	384.3	1207.0	103.4	1.656	.6039
265.3	280	411.1	822.0	385.3	1207.3	102.3	1.639	.6101
268.3	283	412.1	821.3	386.3	1207.6	101.3	1.621	.6164
271.3	286	413.0	820.6	387.3	1207.9	100.3	1.606	.6226
274.3	289	414.0	819.9	388.3	1208.2	99.3	1.591	.6288
277.3	292	415.0	389.2	819.3	1208.5	98.35	1.575	.6350
280.3	295	415.9	390.2	818.6	1208.8	97.42	1.560	.6412
283.3	298	416.9	391.1	818.0	1209.1	96.47	1.545	.6474
285.3	300	417.4	391.9	817.4	1209.3	95.8	1.535	.6515
290.3	305	418.9	394.5	815.2	1209.7	94.37	1.510	.6618
295.3	310	420.5	396.0	814.2	1210.2	92.92	1.488	.6721
300.3	315	421.9	397.6	813.0	1210.6	91.52	1.465	.6824
305.3	320	423.4	399.1	812.0	1211.1	90.16	1.443	.6927
310.3	325	424.8	400.6	810.9	1211.5	88.84	1.422	.7130
315.3	330	426.3	402.1	809.8	1211.9	87.55	1.401	.7133
320.3	335	427.7	403.6	808.8	1212.4	86.31	1.382	.7236
325.3	340	429.1	404.8	808.1	1212.9	85.10	1.394	.7339
330.3	345	430.5	406.0	807.2	1213.3	83.92	1.343	.7442
335.3	350	431.90	407.3	806.4	1213.7	82.71	1.325	.7545
385.3	400	444.9	420.8	796.9	1217.7	72.8	1.167	.8572
435.3	450	456.6	433.2	788.1	1221.3	65.1	1.042	.9595
485.3	500	467.4	444.5	780.0	1224.5	58.8	.942	1.0617
535.3	550	477.5	455.1	772.5	1227.6	53.6	.859	1.1638
585.3	600	486.9	465.2	765.3	1230.5	49.3	.790	1.2659
635.3	650	495.7	474.6	758.6	1233.2	45.6	.731	1.3679
685.3	700	504.1	483.4	752.3	1235.7	42.4	.680	1.4699
735.3	750	512.1	491.9	746.1	1238.0	39.6	.636	1.5720
785.3	800	519.6	499.9	740.4	1240.3	37.1	.597	1.6740
835.3	850	526.8	507.7	734.8	1242.5	34.9	.563	1.7760
885.3	900	533.7	515.0	729.7	1244.7	33.0	.532	1.8780
935.3	950	540.3	523.3	723.4	1246.7	31.4	.505	1.9800
985.3	1000	546.8	529.3	719.4	1248.7	30.0	.480	2.0820

TABLE V.

EXPANSION AND WEIGHT OF WATER AT VARIOUS TEMPERATURES. (HUTTON.)

Temperature.	Relative Volume by Expansion.	Weight of One Cubic Foot.	Weight of One Gallon. English.	Temperature.	Relative Volume by Expansion.	Weight of One Cubic Foot.	Weight of One Gallon. English.
° Fahr.		lb.	lb.	° Fahr.		lb.	lb.
32	1.00000	62.418	10.0101	100	1.00639	62.022	9.947
35	0.99993	62.422	10.0102	105	1.00739	61.960	9.937
				110	1.00889	61.868	9.922
		62.425		115	1.00989	61.807	9.913
39.1	0.99989	Maximum density	10.0112	120	1.01139	61.715	9.897
				125	1.01239	61.654	9.887
40	0.99989	62.425	10.0112	130	1.01390	61.563	9.873
45	0.99993	62.422	10.0103	135	1.01539	61.472	9.859
46	1.00000	62.418	10.0101	140	1.01690	61.381	9.844
50	1.00015	62.409	10.0087	145	1.01839	61.291	9.829
				150	1.01989	61.201	9.815
		62.400		155	1.02164	61.096	9.799
52.3	1.00029	for ordinary calculations	10.0072	160	1.02340	60.991	9.781
				165	1.02589	60.843	9.757
				170	1.02690	60.783	9.748
65	1.00038	62.394	10.0063	175	1.02906	60.665	9.728
60	1.00074	62.372	10.0053	180	1.03100	60.548	9.711
62				185	1.03300	60.430	9.691
Mean				190	1.03500	60.314	9.672
temperature	1.00101	62.355	10.0000	195	1.03700	60.198	9.654
				200	1.03889	60.081	9.635
				205	1.0414	59.93	9.611
65	1.00119	62.344	9.9982	210	1.0434	59.82	9.594
70	1.00160	62.313	9.9933	212	1.0466	59.64	9.565
75	1.00239	62.275	9.9871	230	1.0529	59.36	9.520
80	1.00299	62.232	9.980	250	1.06243	58.75	9.422
85	1.00379	62.182	9.972	300	1.09563	59.97	9.136
90	1.00459	62.133	9.964	400	1.15056	54.25	8.700
95	1.00554	62.074	9.955	500	1.22005	51.16	8.204

To change weight of one gallon English to weight of one gallon United States multiply the figures given above by 0.83295.

Table VI.

TEMPERATURE OF BOILING, BAROMETER, ALTITUDE.

Boiling-point in Deg. Fah.	Barometer, Inches.	Altitude above Sea-level, Feet.	Boiling-point in Deg. Fah.	Barometer, Inches.	Altitude Above Sea-level, Feet.	Boiling-point in Deg. Fah.	Barometer, Inches.	Altitude above Sea-level, Feet.
184	16.79	15,221	196	21.71	8,481	208.0	27.73	2,063
185	17.16	14,649	197	22.17	7,932	208.5	28.00	1,809
186	17.54	14,075	198	22.64	7,381	209	28.29	1,539
187	17.93	13,498	199	23.11	6,843	209.5	28.56	1,290
188	18.32	12,934	200	23.59	6,304	210	28.85	1,025
189	18.72	12,367	201	24.08	5,764	210.5	29.15	754
190	19.13	11,799	202	24.58	5,225	211	29.42	512
191	19.54	11,243	203	25.08	4,697	211.5	29 71	255
192	19.96	10,685	204	25.59	4,169	212	30.00	S. L. = 0
193	20.39	10,127	205	26.11	3,642	212.5	30.30	− 261
194	20.82	9,579	206	26.64	3,115	213	30.59	− 511
195	21.26	9,031	207	27.18	2,589			

Corrections for Temperature.

Mean temp. F. in shade	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
Multiply by	.933	.954	.975	.996	1.016	1.036	1.058	1.079	1.100	1.121	1.142

At the level of the sea, water boils and steam is made at 212° F., and the higher the altitude above sea-level the more easily water boils and steam is made; the lower down in the earth we descend the more difficult it is to make steam.

Table VII.

CHEMICAL COMPOSITION OF SUBSTANCES WITH SYMBOLS.

Substance	Composition.
Acetic acid	$C_2H_4O_2$
Alcohol	C_2H_5OH
Alkali waste	CaS
Alum	$K_2SO_4Al_2 3SO_4$
Alumina	Al_2O_3
Ammonia	NH_3
Ammonium carbonate	$(NH_4)_2CO_3$
Aqua regia	HNO_3+3HCl
Barium carbonate	$BaCO_3$
Barium chloride	$BaCl_2$
Bauxite	$Al_2O_3+2H_2O$
Bitter earth	MgO
Black ash	Na_2CO_3+CaS
Bleaching-powder	$CaOCl_2$
Bone-ash	$Ca_3(PO_4)_2$
Borax	$Na_2B_4O_7+10H_2O$
Boracic acid	BO_3H_3
Boric acid	$H_2B_2O_4$
Calcium bicarbonate	$Ca(HCO_3)_2$
Calcium carbonate	$CaCO_3$
Calcium chloride	$CaCl_2$
Calcium hydrate	$Ca(HO)_2$
Calcium sulphate	$CaSO_4$
Calc-spar	$CaCO_3$
Carbonic acid	CO_2
Carbonic oxide	CO
Caustic lime	$Ca(OH)_2$
Caustic potash	KHO
Caustic soda	NaHO
Chalk	$CaCO_3$
Copperas	$FeSO_4+7H_2O$
Corrosive sublimate	$HgCl_2$
Cream of tartar	$KHC_4H_4O_6$
Dolomite	$MgCO_3+CaCO_3$
Epsom salts	$MgSO_4+7H_2O$
Ferric oxide	Fe_2O_3
Ferric sulphate	$Fe_2(SO_4)_3+9H_2O$
Ferrous carbonate	$FeCO_3$
Ferrous oxide	FeO
Ferrous sulphate	$FeSO_4+7H_2O$
Glauber's salt	$Na_2SO_4+10H_2O$
Gypsum	$CaSO_4+2H_2O$
Hematite	Fe_2O_3
Hydrochloric acid	HCl
Iron-rust	$2FeO_3+3H_2O$
Iron pyrites	FeS_2
Kaolin	$Al_2O_3+2S_iO_2+2H_2O$

CHEMICAL COMPOSITION OF SUBSTANCES WITH SYMBOLS—*Continued.*

Substance.	Composition.
Lime	CaO
Lime (slaked)	$Ca(HO)_2$
Limestone	$CaCO_3$
Magnesium hydrate	$Mg(OH)_2$
Magnesium bicarbonate	$Mg(HCO_3)_2$
Magnesium carbonate	$MgCO_3$
Magnesium chloride	$MgCl_2$
Magnesium sulphate	$MgSO_4$
Marble	$CaCO_2$
Mortar	$Ca(OH_2)+4SiO_2$
Nitre	KNO_3
Nitric acid	HNO_3
Ozone	O_3
Pearlash	$K_2CO_3+2H_2O$
Permanganic acid	$HMnO_4$
Plaster of Paris	$CaSO_4$
Potash	KHO
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